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PERMANENT WAY

ROLLING STOCK

AND

TECHNICAL WORKING

OF

RAILWAYS

WITH AN APPENDIX ON **WORKS**

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BY

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(Matériel des chemins de fer) du jury international, etc.

VOLUME III

WITH ATLAS OF 21 PLATES

TRANSLATED FROM THE FRENCH BY

J. EDWARDS WILSON

LATE ENGINEER IN CHIEF OUDH AND ROHILKUND RAILWAYS

TEXT

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PERMANENT WAY

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RAILWAYS

BOOK FOURTH

STUDY OF THE LOCOMOTIVE

AS A STEAM ENGINE

1. Like every steam engine, the locomotive obtains its mechanical power from the sources of heat, that is to say from a particular class of chemical combinations, the combustion of certain bodies, sometimes wood, turf, almost always coal. The water is only an intermedium between two media maintained at different temperatures, only a vehicle, so to say, which by its change of *state*, the word being taken in its most general sense, receives, stores up , and transmits the power.

For the theoretical engine, the same water brought back to its initial state at the end of each period, would accomplish indefinitely the same evolution, transforming into work the excess of heat which it takes from the hot source over that which it yields to the cold source.

We can unfortunately, on the one hand, recover in the shape of mechanical work, of *vis viva* of mass, only a small portion of the total heat developed by the combustion, that is to say, of the molecular or vibratory *vis viva;* the greater part escapes from this sort of guiding, this transformation of the vibratory movements into movements concordant in way and direction,

by which the heat is converted into work. On the other hand, the mechanical work obtained, applied to the first organ of the engine, cannot itself be completely utilised. In industrial applications, in its turn, it is transformed in part, into heat. The work applied to a file for example, produces not only filings, that is work utilised, but also heat, work not utilised.

The pressures exerted between the parts of machines develop friction. The corresponding moving work, stopped, so to say, on the way, lost as regards the useful effect, returns into the state of heat, and this heat is the more detrimental in as much as it modifies the coefficient of friction, and so the cause and effect react thus on each other. Thence the necessity of very perfect lubrication, so as to maintain this coefficient as low as possible, and consequently the loss of work by its transformation into heat.

When a locomotive draws a train along a horizontal and good permanent way, at a uniform speed, the work transmitted to the driving shaft has little else than the various frictions to overcome, and so transform itself into heat; so that almost all the heat leaving the boiler is ultimately to be found in the same shape in the atmosphere and the bodies in contact.

We shall study successively; 1st. the production of steam; or, in other words, of the utilisable work, and its accumulation in the boiler; 2nd. its more or less complete transmission to the driving shaft.

CHAPTER I.

BOILER PROPER.

§ I. — Preliminaries.

2. It is from the condition, on which we have several times insisted, of the smallness of the weight of the engine (and we may add, of the smallness of its bulk), relatively to its power, that are derived, the essential characters of the boiler - which is the principal element of the weight and of the bulk of a locomotive.

In order that a generator of small weight and small volume containing consequently little water, may produce plenty of steam, the products of combustion must penetrate, so to say, through all the points of this mass of water, and the great heating surface thus obtained, must be above all formed of light, that is to say, thin metallic sides; on the other hand, in order to burn on a grate limited in extent, a quantity of fuel in proportion to the development of the heating surface and with the activity of mean evaporation per unit of surface, a very powerful mechanical draught must be available, the *natural* draught, or that induced by a chimney being evidently impracticable.

The two principles, thanks to which the locomotive fulfils these conditions, are, as every one knows: 1st. the tubular arrangement, that is to say the boiler with inside fire-box pushed, so to pay, to the limit; 2nd. the draught, by the injection into a small rudimentary chimney, of the steam which escapes from the cylinders.

If the condition of lightness and small volume necessarily results from the participation of the locomotive in the movement produced by itself, this character is also in keeping with another character of the service it has to perform : discontinuity. Fixed motors work ordinarily for continuous periods more or less prolonged. Lighting occurring only after pretty considerable intervals, the time and the expense of heat necessary for getting up steam, after complete cooling down, are of no consequence, while the solid mass connected with the boiler, the bulk of the fire-box, protect it against cooling during short stoppages, and form during working, a reservoir of heat,

a sort of regulator, which is able compensate, in part, for irregular and careless stoking. It is otherwise with locomotives. They only remain lighted, generally, for a couple of days, and the smaller their mass, the less fuel their getting up steam requires, and (what is more important still), less time.

3. Invented for the locomotive, the tubular boiler is often employed now-a-days in stationary engines, not only for temporary purposes, for which it is so suitable, but even permanently as well. The advantage it possesses of concentrating great power in small compass may in many cases compensate for the drawback of the necessity of more constant and careful attention; the more so, as, with regard to the utilisation of fuel, it perfectly stands comparison with the best cylindrical forms of boiler, with internal flues.

It is not only, moreover, the boiler of the locomotive, but also, and very frequently, too, the type of its mechanism which is applied to fixed engines. We find in one of the most important categories of *reversing* engines, those used for winding at mines, all the characters of the locomotive, that is to say, two horizontal cylinders with pistons at 90° on the same shaft, and with slide valves worked by a link. The locomotive has created a school; the arrangements which at first characterised it, which there was reason to think were but moderately satisfactory in themselves, and compulsory under the altogether special conditions of its work, thus receive a remarkable practical endorsement, in their very frequent applications, where there is a freedom of choice.

This analogy, so frequent nowadays, between stationary engines and locomotives, is not to be found between these latter and the engines of steam-vessels, in spite of the analogy of their functions, for in this case also it is a question of the motor participating in the movement it imparts to the useful load. But the difference in the conditions under which they act is such as to overpower the similarity of functions, and yet, be it remarked in this case also, in spite of the use of the condenser, a marked tendency to an increase in the pressure, which at present reaches seven atmospheres, even in marine engines, a rise which has become possible, since the adoption of surface condensers has done away with the difficulties, increasing with the pressure, which attend the use of sea-water. If these pressures are still relatively low, it is on account of the enormous thicknesses which would be required for the plates of the bodies of the boilers of very great diameter, of the boilers belonging to the type sanctioned by long practice, but which is departed from sometimes, by approximating then again, to the

locomotive boiler. As to the draught, when it is produced by a steam-jet, this jet is taken directly from the boiler, steam-boat engines naturally profiting, unless in some quite particular cases, by the facilities they find for the condensation of the exhaust steam, which is the more necessary, as the pressure is more limited.

The conditions, so difficult, of placing and fixing marine engines, and the type of propeller, explain the diversity, and even the complication of the types.

It is especially also the example of the locomotive which has dissipated the prejudices which existed against the great velocity of pistons.

In no case nowadays, without excepting locomotives themselves, is piston-speed pushed so far, as in marine engines. The screw has almost universally replaced the paddle-wheel, and independently of the motives special to vessels of war, one of the causes of that preference is the unfavourable position of engines with paddles, struggling against a heavy sea. The shocks of the waves against these enormous wheels, the floats of which offer so great a hold, and are situated so far from the shaft, expose the latter to such efforts, as, in spite of the apparently excessive dimensions given to it, to cause it often to break short off. The paddle-wheel shaft, although with no load to carry is thus often, in reality, placed under much more difficult conditions than the driving axle of a locomotive. As to the screw shaft, the velocity it requires to be driven at is sometimes so great, that it seemed at first impossible to connect the pistons directly to it. But an endeavour was made to suppress the intermediate gearing, and that bold step has been completely endorsed by experience, not only as regards the maintenance of the engine, but also as to the useful effect of the fuel, which appears not only to lose nothing, but even decidedly to gain by the increase, I was about to say the exaggeration, of the speed of the piston.

The suppression of the passive resistances of the gearing, enters for a good deal into this result; but it does not appear to be sufficient in the way of explanation. The rapidity of the movement of the steam, its very short stay in the cylinders, involve consequences, some favourable, others contrary, to the utilisation of its work; and the first seem to carry the day, up to a limit of speed of piston a great deal higher than was supposed.

This fact, which we cannot here dwell on, is not without interest from the point of view of the locomotive; it would be rather curious if, after having by its example, brought stationary engine builders to be less timid on this point of piston speed, it were brought in its turn, by the example of marine engines to extend, on its own account, the limit accepted not without diffi-

culty; and so admit of a reduced diameter for the driving wheels (II. 252), all things besides equal. If this seems little probable, especially on account of the absence of condensation, the fact established for marine engines was not much more so.

§ II. — Elements of the boiler. Outside shell.

4. The boiler is composed of two parts:

1st. The outside shell, including the outside fire-box, the cylindrical barrel, and the smoke box;

2nd. The internal system, forming the heating surface, that is to say, the inside fire-box, and the tubes.

a. The *fire-box* shell is ordinarily a parallelopiped surmounted by a cylindrical top, which is nowadays almost always a continuation of the upper part of the barrel.

The *cloister-arch* dome, springing from the level of the top of the shell, frequently employed by *Stephenson*, has long been given up; it had the drawback of requiring special stays, and of throwing back the centre of gravity of the boiler too far, in engines with overhanging fireboxes. It naturally contained the steam-valve; such indeed was its main object; and as it is especially in the fire-box that the evaporation is most violent, and the quantity of water carried over considerable, this arrangement of the steam-valve has almost gone out, and with it the cloister-arch dome.

Glancing over the plates, it will be readily seen, that the fire-box, and consequently its cover are often wider than the cylindrical barrel (II, Pl. XXII and XXIII, English type; XXVIII and XXIX, Méditerranee; XXXIII and XXXIV Western of France; XLIII and LXV, Western of France; LIII and LIX, *Moscow* to *Koursk;*; LXV and LXVIII, *Santander* to *Alar del Rey*; LXXI and LXXII, *Seraing* engine; LXXV *Steierdorf* engine; LXXIX, *fig.* 3, altered engine of the Eastern of France; *figs.* 7 and 8, Belgian State railways; LXXX, *fig.* 4, *la Rampe;* LXXXVI, *fig.* 16, American engine). Nowadays it is most often preferred, for the barrel to have the same width as the fire-box. Therefrom result at times, difficulties in placing the suspension springs with inside frames, but these are got over by divers contrivances indicated farther back (II. 290); and, as regards the boiler, uniformity is at the same time simpler, and more favourable to resistance. The increase in the section of the barrel, also allows some more tubes to be added, but only in the lower part, in the space *a b c d* (Pl. I, *fig.* 1), the width being limited by that of

the fire-box. The substitution of the section AMBC, for the section *amcd* amounts thus particularly to an increase in the water and steam spaces, and the distance, often too small, of the extreme tubes from the barrel, which is not to be overlooked, from the point of view of cleaning, and easy disengagement of the steam.

Sometimes also the cylindrical barrel, and the top of the fire-box shell, having the same diameter, have not the same axis. The second is a little raised so as to give a more spacious steam dome, and in which the regulator is placed, as in the old *Stephenson* boilers. The high speed engine of the Northern of France. (II, Pl. XXX and XXXII) is so; as it was required to get the load towards the hinder end, on account of the position of the coupled wheels beyond the fire-box, the double drawback was accepted of the position of the intake of the steam, and the somewhat less simple junction of the top of the fire-box shell with the barrel.

Another old arrangement, but still in use at the present time and even more and more so for engines with inside frames, consists in widening out the fire-box shell laterally above the frame plates; this widening out which affects the fire-box shell as well as, the diameter of the barrel, amounts consequently to an increase of the heating surface, and of the water and steam spaces (III, Pl. XXIII; XL, *fig.* 1;XLII, *fig.* 3; XLV, *fig.* 2; XLVI, *fig.* 2; LV, *fig.* 2; LVI, *fig.* 2; LX, *fig.* 1; LXVIII, *fig.* 1; LXX, *fig.* 3). It is clear that the inside-box can only be put in through the top of the fire-box shell before the top is rivetted on, when the widening out is considerable, as in *Koechlin's* boiler (Pl. LVI, *fig.* 2); the *Orleans* boiler (Pl. LX, *figs.* 1 and 2), etc.

The flat sides of the fire-box require *extra* plates, having about the same strength in all directions. This superior quality is necessary particularly for the two cross-plates, which are turned up so as to be joined on to the cylindrical barrel, the top and the sides. The turning over of the edges, done on a cast iron mandrel, by a wooden mallet, requires several heats, but only to a dull red. A great deal of care indeed, as well as nicety is required, so that these thick plates may support the operation without cracks occurring.

The layers comprised between the covering-pieces of the pile for plates are crossed so as to get equality of strength; but the rows parallel to the rolls are doubled, so as to diminish the influence of the rolling.

The very process of turning up the edges, is a sort of guarantee of the quality of the plates, which, however, may have undergone deterioration without showing it by any external sign. It is on this ground that many English engine builders keep to the old method of joining the plates by means of angle-irons (II, Pl. XXIII, Great Eastern engine constructed

at the *Creusot* works), in spite of the evident advantage attached to the reduction of the number of the lines of riveting, lines of weakness as regards resistance and as regards leakage.

The flanges turned up on the front and back plates, and on which is fixed the top fire-boxshell are ordinarily both inside (II, Pl. XXX); sometimes however, the back plate is turned over the other way, examples : boilers of the *Orleans* eightwheeled engine (II, Pl. XLVIII; ten wheeled engine of the same lines, Pl. LIX). The advantage is that in case of leaks, the rivets can then be replaced from the outside. But, at the same time, all else equal, the capacity of the fire-box is a little reduced.

In France the edges of the plates are often turned over too sharp. It is desirable to follow the example of different builders, among others, M. *Börsig*, who bend the edges of the plates over to a radius, which ought not to be less than three inches.

5. *b. Cylindrical barrel.* — If the width of the boiler is limited, and in an absolute manner when the wheels are of large diameter (II, 235), it is not the same as regards its height. Thus some builders had adopted an ellipse with a vertical axis, for the section of the barrel (boiler of the *Seraing engine*, II, Pl. LXXII), and *Kessler* for some years frequently adopted this section. Carrying the principle to excess, he has even constructed boilers formed of two cylinders penetrating each other; the lower segment was occupied by the water and the tubes, the other by the steam; but experience has condemned these contrivances. The moment the simple circular form is departed from, stays are required along the small axis in the first case (II, Pl. LXXII, τ, τ, *fig.* 2), and along the common chord in the second; and in spite of that, safety is always more or less endangered; these faulty arrangements have caused several explosions. We shall see, however, the elliptic section come up again in one of Mr. *Fairlie's* last types (Pl. II, *fig.* 1).

The iron plates which constitute the cylindrical barrel should always have their length, that is to say the direction of the rolling, perpendicular to the axis. Formerly, on the *Orleans* Railway, for example, the reverse arrangement was preferred; the shell formed of plates of the same length as itself, had only longitudinal lines of rivets, but it is these which are the most dangerous. The first arrangement is alone adopted at the present day, and rightly; the resistance of plates to fracture by extension is almost always less when the strain is directed normally to the rolling than when the two directions coincide. The difference, less marked, in general, the better the quality of the plates, can rarely be neglected with respect to those which

are made use of for boiler work; and as, under the action of an internal pressure the molecular tension developed in the metal is twice as great normally to the axis as along the direction thereof, the greatest resistance should be opposed to the greatest strain; and this ground would still exist even for plates having the same resistance in the two directions, because the total length of the lines of rivets parallel to the axis must always be reduced to a minimum; thus the barrel is composed of hoops, formed as much as possible each one of a single plate, so that the total length of longitudinal riveting is equal to the length of the barrel; and care is taken that with each of the hoops, three in number for ordinary lengths, this riveting which is kept at the same time above the level of the water, goes from one side of the boiler to the other, so as to avoid the continuity of the line of least resistance.

We know that the form of equilibrium of a solid placed on two supports, acted on by a force p uniformly and normally distributed over its periphery, is an arc of a circle, and that the force p, the diameter d and the tangential effort t are connected by the relation: $t = \frac{pd}{2}$. The tangential resistance is besides $\mathrm{R}\,e$, e being the thickness and R the molecular strain, in traction or compresion, according to the direction of p. We thus have:

$$\frac{pd}{2} = \mathrm{R}e.$$

In the particular case in question the ratio of the strains R, R_1 developed in the metal, normal to the axis and normal to the cross-sections, can besides be immediately established. We have:

1. For the one, considering the diametral plane A B (Pl. I, *fig.* 2) and the unit of length of the cylinder:

$$p \times d = 2\mathrm{R}e \ldots \text{ (1)}, \quad \text{whence} \quad \mathrm{R} = \frac{pd}{2e}.$$

2. For the other:

$$p \times \frac{1}{4}\pi d^2 = \frac{1}{4}\pi[(d+2e)^2 - d^2]\,\mathrm{R}_1 \ldots \text{ (2)}, \quad \text{whence} \quad \mathrm{R}_1 = \frac{pd^2}{4(de+e^2)},$$

Or, e being very small against d,

$$\mathrm{R}_1 = \frac{pd}{4e} = \frac{\mathrm{R}}{2}.$$

This smallness of e against d is besides necessary, in order that the relations (1) and (2) may be pretly nearly exact. They suppose in effect the strain uniformly distributed throughout the sections of the metal, and it is by no means so when the thickness is comparable to the diameter. If we conceive the cylindrical side divided into concentric rings of very small thickness

compared to the internal diameter of the boiler, the first ring towards the interior receives a greater pressure than that which it transmits to the second, which in its turn transmits a reduced pressure to the third, and so on. If the internal pressure is pushed to the limit, as far as breaking, the first ring gives way the first; the pressure is then altogether exerted on the second, which gives way in its turn. Breaking is thus effected successively, and not simultaneously. Without doubt, the hypothesis of the independent rings simply fitting into each other like hoops, is not in accordance with reality; but it is very nearly in that way that the action takes place, as is proved by the manner in which very thick sides tear. M. *Collignon* justly remarks(*) that the hypothesis of the uniformity of distribution leads, as a necessary consequence, to an increase of thickness under the action of the internal tension, while it is on the contrary a *contraction* which a rod undergoes when drawn in the direction of its length. This hypothesis thus implies a contradiction, in the case where the thickness is not very small.

This estimation of the molecular tension along one direction, abstraction made of the strain exerted along the direction at right angles, is indeed only an approximation. The existence of the ends, and the shape thereof, affect the strain R. If the ends are spherical, their radius and the thickness of the plate can be determined by the condition that the cylinder and the spherical portion tend to expand equally, and consequently without mutual reaction; but if the ends are flat, as is the case in locomotives, the cylinder bulges out in the middle, flexion intervenes, and the length of the cylinder reacts on the tension R; but some experiments of *Fairbairn* tend to prove that this effect, limited by the transverse joints however, may be neglected in practice. There is no use in dwelling here on a point the interest in which is only theoretical, and with respect to which we confine ourselves to referring to special works on the subject(**).

In tubular boilers, the molecular effort, normal to the cross sections, is not even the one-half of the effort normal to the axis, the total pressure on the ends being diminished by that which corresponds to the sections of the tubes; but they exert, it is true, on the tube-plates, on account of their tendency to expand more than the external envelope, a thrust which is brought upon the latter.

Each hoop can be rivetted on to itself and on to its neighbours, either by lapping, or by a covering plate.

Lap-joints are mostly in use, although applied to the longitudinal joints

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(*) *Cours de mécanique appliquée aux constructions*, 1st part, page 368. *Dunod, Paris*, 1869

(**) *Grashof. Die Festigkeitlehre*, pages 235 and foll. *R. Gaertner, Berlin*, 1866.

they have the drawback of altering the circular shape a little, and much more, the uniformity of the distribution of the strains near the joint. They should always however, be made with two rows, so as to reduce the disadvantage of their position. As to the joining of the intermediate hoop or hoops, these may be either brought over the others or let in at the two ends (II, Pl. XXIV, *fig.* 4), or let in on one side, and brought over on the other (English *telescopic* arrangement; example : American engine of the Great Northern, II, Pl. LXXV, *fig.* 4).

The hoops are sometimes joined together with two rows of rivets, but wrongly. It is useless to strengthen points already relatively strong. Some builders state, it is true, that these lines of riveting are the most subject to leakage.

The inequality, slight however, of the diameters of the hoops disappears, and that of the strain on the metal diminishes, by the application of a circular covering plate (II, Pl. XXVIII).

To realise all the advantages of rivetting with covering plates, it is expedient in general, as we shall presently see (56 and following) that it should be double; but in the actual case the simple external covering plate seems preferable; a thick ring, taking in the two hoops, forms especially if it is itself welded together, a regular hoop, which, dividing the cylindrical barrel into pretty short lengths, thus eliminates the unfavorable influence of the length, and is equivalent to a certain uniform extra thickness.

6. *b*. As an example of the modifications at times made in the shapes which seem sanctioned by long practice, let us note in passing, and although it cannot be applied to locomotives, the method pointed out in England by Mr. *Adamson*, and recently applied by MM. *Sulzer Frères* of *Winterthur*, to their fixed boilers with inside flue (Pl. I, *fig.* 3) (*). The inside edges of the lengths of the cylindrical flue are turned up outside, and are riveted together with the interposition of a sheet iron ring, the object of which is especially to allow the caulking of the joint at A. The rivets have thus got both their heads in the water; the inside flue, the variations in temperature of which are greater than those of the external envelope, expands more freely, on account of its longitudinal flexibility, and the whole thing thus escapes a very serious source of strain; and further, the pressure of the steam tends to tighten the joint. But it is especially by the transversal stiffness which it gives, that this method of joining is so suitable

(*) *Bulletin de Mulhouse*, 1873. Article of MM. *Meunier-Dollfus* and *Hallauer*.

for tubes pressed from the outside. The only objection is the increase of longitudinal strain put on the rivets, a drawback partly compensated for however by the increase in the number thereof.

3. *c. Smoke-box.* — The smoke-box is ordinarily formed nowadays by the continuation of the cylindrical shell. The tube-plate which separates them is thus circular, and has its edge turned up all round to fit into the barrel, which is itself continued a little beyond, and takes the smoke-box.

This capacity is only subjected to the external pressure, which is very slight, arising from the rarefaction effected by the exhaust steam on the gaseous current. These gases before being ejected from the chimney, are collected therein to be subjected to the draught of the blast; therein also are deposited the ashes and the pieces of unburnt coal that the current brings over with it. Sometimes the small coal carried over by too active a draught, accumulates in the smoke-box and takes fire there, especially if the external air gets in directly through a badly closing door. A fire ought not to occur in the smoke-box, except by negligence; if, however, it should occur, the driver ought immediately to put it out by throwing water on it, and empty the box. A small special tube is often provided for this purpose.

An inside casing of sheet iron going only half way up the smoke-box, protects it against the erosion produced by this little secondary fire-box.

In some engines, for example in the *Steierdorf* (II. Pl. LXXV), a hopper has been adapted to the bottom of the cylindrical smoke-box for the discharge of the cinders, and the coal dust. It is closed by a register worked from the outside, and which allows the box to be emptied without opening the door, and without dirtying the valve-gear.

Communicating on the one side with the fire-box (by means of the tubes), and on the other with the atmosphere, (by means of the chimney), this space should be perfectly tight over the whole of the rest of its surface, in order that the draught may only be exerted on the gases coming from the fire-box. The large door with which it is provided and which is necessary for keeping the tubes clean, for placing, cleaning and extracting them, for removing the small pieces of unburnt coal, etc., ought thus to close hermetically. For a long time the smoke-box was provided with a register having a long rod, by means of which the driver could at will admit therein air from the outside. But means of checking the draught are not wanting, as will be seen; drivers scarcely ever made use of the cold air register, and it has disappeared.

The smoke-box does not, by a long way, require to be as solidly constitu-

ted as the boiler; but its resistance is not determined by the consideration of the slight effective pressure to which it is subjected from without. It carries in effect the chimney, the mass of which is inconsiderable, but the vibrations of which transmit strains which fatigue the smoke-box very much. The smoke-box is often, although not subjected to the pressure of the steam, the part of the exterior envelope which lasts the least.

M. *May* of the North Eastern of Switzerland, applies a slight modification to his engines : the slanting of the tube-plate; he thinks that there results from this an improvement of the draught, the currents which rush out of the tubes running towards the chimney without interfering with each other. This opinion does not appear to have been borne out by precise experiment.

8. *d. Chimney.* — The part it has to perform has evidently nothing in common with that of the enormous stacks in masonry or iron, of powerful stationary boilers. With a height and section necessarily insignificant, the difference between the weights of the two columns of air, one at the external temperature, the other at the temperature of 650° F. or indeed of 750° F. is a fraction altogether trivial, of the motive power necessary to maintain the draught. In several of his engines, for want of height M. *Petiet* placed the chimney horizontally, (II, Pl. LXI, engine with twelve wheels coupled; Pl. LXXVIII, passenger engine with four cylinders, called *steep-gradient* engine, etc.). The draught was not thereby affected; the direction of the chimney is thus indifferent. Turning the chimney down was besides necessary; for the length of the chimney, or more exactly, the ratio of that length to the diameter ought not, as we shall see farther on, to go below a certain limit. The chimney in the locomotive is not without some analogy with the bore of a gun; if the steam rushed into the atmosphere through too short a tube, its impulsions and consequently its action in carrying off the gases would be reduced by that very fact.

The height of a chimney can be increased (or more correctly, its length) and the volume of the smoke-box reduced at the same time (which seemed *a priori* to be advantageous, although the contrary may be more probable), by continuing the first within the second, dividing it in that case by a horizontal diaphragm placed above the tubes (II, Pl. XXX).[1] The real advantage of this arrangement is perhaps the more solid installation for the chimney and less fatigue for the smoke-box. We shall examine also in treating of the draught (111 and following), some other peculiarities in the form of chimnies and the experimental researches made thereon.

9. *Direct supports of the boiler.* — The boiler ought to be withdrawn as much as possible from all other efforts than those which result from the tension of the steam. The frame ought to offer it points of support, the more numerous the longer it is, and which leave it free to yield to the variations of temperature. The boiler is only fixed to the frame invariably on each side at the front end, and all the other supports are arranged so as to allow it to slide. This is also in the interest of the frame itself, which has the task of preserving the invariability of the distance between the axles, and which must therefore be prevented from receiving, slight, although not unimportant deformations which would be produced by the solid connection.

Brackets riveted on one side to the smoke-box, on the other to the longitudinals, form the fixed connection of the smoke-box with the frame. In short boilers, the cylindrical barrel might, on account of its shortness, and the rigidity which it owes to its hollow shape, do without intermediate supports; but with the actual lengths, one, and often two and even three are required; these supports are at times simple angle pieces riveted by their two branches on to the side of the barrel, and present at their junction a shoulder which rests on the longitudinal, on which it slides (II, Pl. XL, *fig.* 3 and Pl. XLII, *fig.* 2). Nowadays to each pair of lateral supports is preferred an understay in T iron riveted on to the longitudinals and on which the boiler can slide (II, Pl. XLVII, *fig.* 2 and Pl. LII, *figs.* 1 and 2, *s*, *s*). It ought to rest on this piece, not directly, but by intermediate plates of iron fixed by rivets with countersunk heads, the ones to the barrels, the other to the support. These intermediate pieces, having at the same time great enough surface to distribute the pressure, alone take the sliding and consequently the wear.

These understays have also the advantage of tying the longitudinals, a part equally fulfilled by simple gusset pieces, but by the intermedium of the boiler.

With inside longitudinals, the fire-box rests thereon by two brackets riveted to the side of the boiler (II, Pl. XXXI, LXVII and LXVIII).

A different arrangement is sometimes applied to engines with inside frames, with small wheels and shallow fire-boxes, the frame of which comes very nearly to the height of the longitudinal. On the latter is riveted a plate carrying a stout spindle, to which is suspended a bracket on which the frame rests. To the variations of length correspond slight oscillations of the bracket on each side of the vertical, through a distance reduced for the friction, brought on to the spindle.

Too much attention cannot be paid to rendering the boiler free for expan-

sion. When its supports are, or become fixed, the strains developed in the region of the points where they are attached to the boiler, determine in the latter, changes upon which we shall return in examining analogous effects due to other causes.

As has been already said (II, 233), the much simpler application of the boiler on to the frame is one of the most powerful grounds, in favour of the inside or double frame. With a simple outside frame, to set the boiler up solidly, requires, in order to get over the space occupied by the wheels, supports greatly projecting, and consequently requiring to be very solidly constituted (examples : *Sigl's* engine with four wheels coupled, II, Pl. XXVI and XXVII, *fig.* 4; S. Pl. XXXIV, *fig.* 2; Pl. LXX, *fig.* 1).

Sometimes, with the double frame a lateral development is given to these supports, great enough for them to rest on the outside longitudinal (high speed engine of the Northern of France, II, Pl. XXXII, *figs.* 4, 5; S, S, supports of the cylindrical barrel); these are cut out of the same plate which is continued below and serves at the same time as support for the piston slides.

10. Certain engines in which the fire-box does not go down low, with inside frames and small wheels, the fire-box, broader than this frame, is placed directly on the longitudinals. Such was the case with the twelve wheeled engine of the Northern of France (II, Pl. LXI and LXII), in which the firebox passed relatively beyond the wheels themselves. If we speak in the past tense, it is because this type has disappeared. We said farther back (II, 262) that the engineers had been led to regret having admitted proportions absolutely unusual for the evaporating apparatus. This regret ended in a radical measure : the complete alteration of the engines. Instead of replacing the boiler, a course was adopted which seems to indicate a reaction of the ideas which were in force on the Northern of France regarding single engines of very great power, and which have been discussed (II, 263). Cutting the longitudinals through the middle and applying an ordinary boiler on each of the partial frames, gives two engines, with six coupled wheels, suitable for station work. In this derived type, as in the first, the fire-box frame is placed on the inside longitudinals, an arrangement possible only with wheels small enough to leave the upper plane of the longitudinals free, and when the *relative* great height of the boiler does not lead to too great an absolute elevation.

§ III. — Inside system of the boiler.

11. *a. Inside fire-box.* — The inside fire-box is, like the outside shell, open at the bottom, and its sides, excepting the roof, which is ordinarily flat, are parallel to those of the outside shell; to which they are fixed by the bottom, sometimes by double angle irons, but almost always by a forged ring of iron.

In Europe, the inside box is always made of copper plates, in spite of the rapid decrease in the tenacity of that metal under the influence of heat; its resistance to extension is reduced, at a red heat, by 90 per cent.; at 660° F. (a point at which the resistance of iron is still intact), by 25 per cent. But iron plates would be rapidly destroyed by the combined action of the high temperature and of the sulphur, from which the fuel, even coke, is rarely exempt, and leakage. There is however no absolute impossibility, especially for iron plates of superior quality, which may be made thin and the face of which, in contact with the fire, is consequently at a less elevated temperature than thicker plates. Thus the use of iron is widely spread in the United States, where the plates are of very good quality and where they do not fear besides to adopt, under the same circumstances, much less thicknesses than in Europe. It is also a question of water. The fire-boxes, in Swedish iron of the first quality, tried some years ago on the line from *Cologne* to *Minden*, gave bad results; the boxes of two large engines had to be replaced at the end of thirteen months. Cracks had formed near the stays as well as the flanges. The stays were also iron. The bad quality of the water, and the adhesion of tartar, more marked than with copper, may have contributed to this negative result.

Copper fire-boxes are almost always formed of three plates, one for the back, another for the front (tube-plates), and the third forming the roof and the two sides; the two first turned over all round, excepting at the lower edge fixed to the iron ring, are attached to the third by copper rivets, ordinarily one row. The front plate has holes in it to receive the tubes, and the other an opening, corresponding to a similar opening made in the parallel plate of the outside shell. A forged iron ring contained between these two sides fixed thereto by rivets passing through the three thicknesses, closes round the opening occupied by the hinged door, from the water.

On the Bavarian State railway, to stiffen the tube-plate and prevent the holes becoming oval, the central vertical row of tubes is sacrificed, and on

the place thereof is rivetted a T iron, on the side next the water. The corresponding surface of the front tube-plate becoming free also, advantage is taken thereof to stiffen it in the same way, although it has not, like the first (32), any vertical strain to support. But like the other, it is strained, and more so indeed by the thrust of the tubes (5). Placed very nearly under the conditions of a plate solidly fixed round its periphery, it undergoes in that region, under the action of the repeated deflections determined therein by that thrust, a change shown by the formation of a furrow gradually deepening.

12. *Grate.* — It is formed of longitudinal bars ordinarily of wrought iron, placed on supports equally of iron, with play enough to allow for their expansion.

It ought to be brought up high enough so that there may be two inches between the upper surface of the bars and that of the fire box ring. This precaution, which we shall see to be necessary (36) for facility of cleaning, is sometimes neglected.

The distance between the bars, their breadth and consequently also their length depend on the nature of the fuel, on its state of division, and of its thickness over the grate. It is necessary on the one hand, to leave a quantity of openings sufficient for the admission of the air, and on the other, to prevent the fuel sifting through. Under the influence of the jolting, the loss of fuel during running is often considerable; the bars, when out of shape and worm, frequently aggravate this.

In principle the free section ought to be as great as possible, although within certain limits it has not much influence; it is less in effect, the grate which chokes the air passages than the fuel itself. The ratio the sum of the openings bears to the total section, ordinarily equal to about $\frac{1}{4}$ in stationary boilers, is greater in locomotives : often $\frac{3}{8}$ or even $\frac{1}{2}$.

The space having to be less the finer the coal is, and the bar shorter the narrower it is, thus for large fire-boxes, burning pit-coal and druss, we have grates formed of a number of very short, narrow bars, placed very close together, and resting on intermediate supports (Pl. I, *fig.* 4).

Cast iron has been and still is in use on several German railways. It does not appear to suit coal, which produces much slag; however the Northern of France employs it exclusively; short bars cast in groups of three (II, Pl. XXXI) or even of four, being much more economical and simpler in use than separarate bars of wrought iron. In the United States, wrought and

cast iron have been employed in the form of hollow tubes with water circulating through them, to avoid the prompt destruction of the bars under the influence of the high temperature developed by anthracite. *Grant's* engine exhibited in 1867, presented this peculiarity; all the fixed portion of the grate was formed of wrought iron tubes with water circulating through them.

The space between the bars is ordinarily regulated by the horizontal widening out of their bearings on their supports, and sometimes also by intermediate projections. Their cross section is a trapezium, in order that the fragments which have been able to get through, may fall out at once, and so not obstruct the passage of the air. The trapezium is often surmounted by a rectangular extension for the purpose of keeping the spaces constant, in spite of the wear, which naturally attacks the upper part more especially (Pl. I, *fig.* 5). We may remark on this subject, that going out of shape is a very serious cause of deterioration, less for the bars which bend than for those which resist. A bar keeping its shape between two others which yield, gets more or less into the fire, and as the air does not cool it, burns.

On the *Orleans* Railway, a simpler form is applied (*Raymondiere's* grate, II, Pl. LIX). The bar is a band of flat iron 0,39 inch in thickness, placed on its edge. Snap-headed rivets maintain the distance apart, fixed also at 0,39 inch; there is alternately a bar with rivets, and one without rivets. These thin bars, only touching at a few points by the heads of the rivets, are so swept over by the air that their temperature is prevented from rising too high. In the example pointed out, the bar, 6,66 feet long, carries seven rivets.

In the engine constructed at the *Creusot* for the Great Eastern (II, Pl. XXIII), the bars, placed on knife-edges, are, during running, in a constant state of jolting, which is favorable to the fall of the cinders and prevents slag adhering.

In such matters, moreover, there is nothing general, and the details of the grate ought, as much as possible, to be appropriated to the special nature of the fuel and to the physical states through which it passes under the influence of the combustion. Care must be taken, however, not to specialise too much; intelligent stoking, as experience proves more and more, may in the same fire-box, but with more or less work, get a good result out of coals very different in their nature, their purity and their physical state. Some coals leave a light refractory ash, which is carried over in greater or less proportion into the smoke box, and which in any case does not obstruct the passage of the air nor corrode the bars. Others swell, stick together, and form on the grate, especially if the depth of fuel is considerable, a sort

of plug almost impermeable to the air, and which requires almost constant work on the part of the stoker. Others again burst into small fragments, which fall through the spaces, if these are too large; and block them up if they are too small. Others form a clinker more or less abundant, more or less fusible, which attaches itself to the bars, and at times corrodes them with extreme rapidity. Others lastly, such as many anthracites, although very pure, soften and distort the bars by the high temperature developed at their very surface, to such a point as to render the work very difficult.

13. *Use of crude coal.* — We lay aside the disadvantage of the smoke, which will be the object of a special investigation. Let us only bear in mind here that it was especially on account of the smoke that the exclusive use of coke was for so long a time inevitable, at least for passenger trains. At the same time some of the draw-backs which we have just enumerated, were partly got rid of. But at what a price! not only dearer was paid for a fuel which was not worth more, but was often indeed worth less than the coal from which it was made, and all coals unsuitable for coke burning were objected to : and how numerous these are need scarcely be said. In 1851, the author of this work expressed his surprise that such an onerous situation was borne with so much resignation, and he added :

" One can understand that previous carbonisation may be often indispensable in metallurgical operations, but it is difficult to admit this to be so where it is only a question definitively of the production of steam (*). " Nowadays, locomotives consume little but crude coal; but what a time has been required to arrive at this! However, the most serious of the difficulties to overcome, so long as it was a question only of substituting large coal and block fuel for coke, was routine. When it was at last decided to enter on this path, much astonishment was felt (and there was really no grounds for it) to see the difficulties evaporate in most cases. It was found that coal, more inflammable and more dense than coke, insures a more economical and abundant production of steam in the same fire-boxes; that, provided it be not too sulphurous, it is more favorable for the preservation of the boxes and of the tubes; that the stoking of the fire is easier; that the pressure keeps up better with a less blast, and is got up much easier.

But, restricted to large pieces, the adoption of coal would only have been a very incomplete progress; the screening of the large coal especially, when

(*) *Emploi de la houille et du coke dans les locomotives. — Annales des mines*, 1851, vol. XIX, page 428.

very friable, leaving considerable quantities of dust, the question was particularly to apply the latter also, to the production of steam. Mining interests as well as railways were equally interested in the success of the result.

Compressing druss into blocks is one solution; it amounts to large coal, and acts the same on the grate. But the expense of manufacture is considerable (at least 5 or 6 shillings per ton), and it was a matter of importance to get rid of it by burning rough coal, and even only at need the druss which can be in any way brought into use. This necessity has become of more consequence still on account of the enormous rise in the price of coal. This problem is the only one which presented serious difficulties and which required special arrangements: these arose too, directly from the physical state of the fuel.

With coke, very defective proportions of the fire-boxes had been got to; their horizontal section, and consequently the grate, was much too small relatively to the heating surface of the tubes. To be able to burn in the unit of time on these little grates a quantity of coke in proportion to the quantity of steam to be produced, it was necessary to have a sufficient mass in ignition, and to compensate thus for the smallness of the section by a regular excess of thickness of fuel on the grate; hence those very deep fire-boxes, which are gradually disappearing. A wrong advantage, so to say, was taken of the property which coke has of burning without obstructing the spaces between the pieces. But the resistance to the draught became excessive, and to overcome it the blast had to be very strong, at least with hard coke, difficult of combustion, such as that in use in France.

With coal in pieces, the conditions already began to change: the swelling and agglutination led to running with a lower fire. But with rough coal and especially with druss, even of a suitable nature, that is to say half gaseous, the conditions change completely; there must be at the same time : 1st, a very reduced thickness of fuel, sometimes down to two inches, and consequently a very large surface in order to have a sufficient mass of fuel; this large surface, to be obtained specially by an increase in the length, the width being limited; 2nd, very small spaces, (0,20 inch only for fine coal), between the bars to prevent sifting through, and consequently very narrow bars in order to give a sufficient quantity of spaces; 3rd, on account of their slight section, very short bars, and consequently the long grate formed of a series of bars placed end to end, on intermediate supports; 4th, a very large door, with two flaps going down very low, often indeed as far as the grate, allowing all its points to be got at with the pick: a condition all the more necessary as the space between the bars being

reduced to a fraction of an inch does not allow the fire to be raked from underneath, and that if clinker forms, it will have to be got out at need through the door, by means of a sort of hooked fork. Thus modified, the locomotive boiler approximates greatly to stationary boilers.

These arrangements, the germ of which is to be found in some American locomotives, and in the type created by MM. *Behne* and *Kool* in Hanover (II, Pl. LXXXVI, *figs.* 2 and 3), were only fully carried out by M. *Belpaire*, chief-engineer of the Belgian State Railway (Pl. I, *fig.* 4). They have become general in Belgium and on other lines, as the Northern of France, for example, on which rough coal forms at the present time more than 50 per cent of the total consumption; a proportion which will go on increasing as the small boxes, which only admitted large coal, give place to the large grate type. The door going down as far as the bottom of the grate was only given up on the Northern of France, because of its rapid destruction.

This necessity of an alteration in the fire-boxes explains, partly at least, why some railways burn only large coal. The Eastern of France, for example, is still at "*gailletterie*" (from *Saarbrücke*) and block fuel (from the North, and from Belgium).

Between the locomotive which burnt coke and the locomotive burning rough coal, is already a progress of very great economical import. No doubt the range of fine coals capable of being used in locomotives will be ultimately extended, and the type of the *Belpaire* boiler will become more and more general.

There is however a reserve to be made on the subject of express trains; the attention of the driver of these should be constantly given to all parts of his engine, to the road, to the signals especially, and his attention must be by no means taken up by too much attention to the fire.

We have already pointed out (II, 271) a very important consequence of raising the grate and consequently the frame of the fire-box : it is the freedom given thereby in the distribution of the axles under the boiler. Thus it has been possible, without raising the boiler too high, to put an axle under the fire-box, not only in slow speed, and consequently small wheeled engines (II, Pl. LVIII and LIX ten wheeled *Orleans* engine; Pl. LXI and LXII, twelve wheeled Northern of France engine; Pl. LXIII, LXV and LXVI, *Vaessen* engine; Pl. LXIX Eastern of France, driving-tender engine; Pl. LXX Central Belgium driving-tender engine), but also in high speed engines, like those of the Belgian State Lines (Pl. LXXVIII, *fig.* 6).

This faculty is of such value that it has long been tried for, at least within certain limits, by a slight modification of the ordinary box. A blunted

corner cut off towards the back of the fire-box allows an axle to be got in more or less under the grate; the Great Eastern engine (II, Pl. XXIII), and especially *Borsig's* (Pl. XXIV), offer examples of this.

The inclination of the grate, a natural consequence of this arrangement, facilitates the stoking at the same time, above all if the coals stick; the fuel put on at the door descends by itself on this inclined plane, the slope of which ought to be at the same time in ratio with the nature of the coal; to keep the far end of the long grate full, it is no longer necessary to take the trouble of pitching the coal in with the shovel; it is sufficient to give the mass of coal a push from time to time in order to facilitate its descent.

14. *Dropping the fire.* — It is necessary for the driver to be able to throw his fire down rapidly in certain cases; for example, if the water supply, pumps or injectors should refuse to work. For small fire-boxes it was sufficient to knock out a few bars; but it is preferable and more expeditious to empty the whole grate at once. Grates are divided in this respect into two classes: those which are removed entire, and they should then have only a slight length, as in the Western of France engines (II, Pl. XXXIV and XLIV), or half only (Pl. XXIII, XLI, XL and LXXV, *fig.* 4), and those which are provided with a special balanced appendage, simply swinging on an axis, and thus dispensing with the troublesome job of putting back the bars one by one as they have been thrown down on the line or into the ash pan (II, Pl. XXIV, XXX, XXXVI, LVI and LVXI).

In *Kœchlin's* eight wheels coupled engine (II, Pl. LVI), the *fire-dropper j* is connected by two rods with the front part of the bottom of the ash-pan, so that when it acts, the coal falls on the line, instead of accumulating in the ash pan. This last appliance, the principal function of which, or at least its regulatory function being to prevent a cause of fire, belongs to safety apparatuses; we shall therefore place it among those. The fire-dropper serves also to get out by the front, over the ash-pit, the lump of clinker which often forms on the grate.

15. *Water spaces in the fire-box.* — The sides of the fire-box forms the direct heating surface; its evaporative power is much greater than the mean power of the tubes (19), especially if they are very long, and very numerous, and consequently of small diameter. It has been endeavoured to increase the direct surface by adding a water space to the fire-box, placed vertically either lengthwise or across. In the first case, it came from the roof, went down to within a short distance from the grate, thus dividing the fire-box

into two compartments, each of which had its own door. So as not to lose tubes, it stopped at a certain distance from the tube plate; the flame thus played completely round it, but its form was complicated; it was inconvenient for clearing the tubes which it was in front of, and for stoking. Applied at the same time to fire-boxes which were already too small, it had the main drawback of reducing still further the already insufficient fuel space, forcing the thickness thereof to be still more excessive, and rendering combustion more difficult by the very fact of the division of the fuel into two distinct masses. Far from remedying the smallness of the fire-box, this arrangement, on the contrary, generally increased its drawbacks.

Placed crossways, towards the bottom, so as not to cover the tubes, the height of the water space could only be slight, because it was necessary that the front compartment of the fire-box should always be accessible for stoking and feeding the fire-box. Giving thus additional heating surface than the preceding, it had scarcely less drawbacks. This second type however, is still to be found in some new engines (example : 6 wheels coupled engines with reheater, on the *Stockton* and *Darlington* railway).

These water spaces, are strained too, particularly the second, by the want of freedom and of expansion and contraction, have thus almost entirely disappeared, unless, as we shall see, in M. *Tenbrincks* fire-box, of which they form an essential part for the consumption of the smoke, and in which besides they escape by their position and their mode of connection, from the principal objections raised by the preceding ones.

It is also to fire-boxes with water spaces that Mr. *Mc Connell's* boiler belongs. It was continued by a sort of pocket into the interior of the cylindrical barrel, where it formed a combustion chamber; the tubes, shortened by so much, and of very small diameter, took up the rest of the barrel; but the experience of this combination of large fire-box and small grate, was not satisfactory. Coal, which Mr. *Mc Connell* had in view, requires above all a large grate; and the best combustion chamber is a large fire-box.

Nowadays a large direct heating surface is obtained by giving the fire-box very large dimensions, as in the *Belpaire* boiler, and not in complicating its shape. The total length of the boiler being limited, the lengthening of the fire-box involves the shortening of the tubes, whence results a much more favorable ratio between the two elements of the surface, if not to economy of fuel, at least to the power and lightness of the engine; and as we have seen, these are main considerations.

The fire-box of boilers which run on very steep gradients present often one peculiarity : a sloping of the roof, to such an extent that on the greatest in-

clination it may be parallel to the rails. This fact and the grounds for it have been already pointed out (II, 275). The *Fell* engines of Mount Cenis offer an example of this (II, Pl. LXXXI, *fig.* 1).

The upper part of the tube plate is always thicker than the other plates. This extra thickness has for object to put this plate, which has to be full of holes, in a position to resist the strains which act on it, and particularly the load of the roof; but above all to insure the joints being stanch (22 and foll.).

16. The actions to which this plate is subjected induced Mr. *Webb*, locomotive engineer of the London and North-Western Railway, to introduce modifications in the construction of the fire-box which deserve to be noticed (Pl. I, *fig.* 6). One plate forms the roof; another forms the four vertical sides, minus the tube portion, which is brought on separately. This portion can be thus replaced without requiring the costly operation of taking down the fire-box. A small slip of copper placed between the edges allows the joint to be made inside the fire-box.

17. *Tubes.* — The principle imagined by M. *Séguin*, of a number of small tubes running through the water, and along which the current of gases is, so to say, drawn out and robbed of its heat, is so thoroughly appropriate to the whole of the conditions under which locomotive work, that none of the endeavours made to get rid of it has succeeded, in any serious application. M. *Belleville* has endeavoured to extend to the locomotive the principle of his generator, which principle is the reverse of the former one as in that case the water fills the tubes, which are passed over *externally* by the gases. But a trial made on the Eastern of France only confirmed the superiority of the classical arrangement, with respect to evaporative power and facility of maintenance. A type of boiler has also been tried in the United States which, while preserving the ordinary form as a whole, has for peculiar feature the introduction of water into the tubes. But there is no advantage in dwelling on an arrangement which has also been formally condemned by experience.

One example is sufficient to give an idea of the proportions in which the tubes increase on the one hand, the gross heating surface, and on the other the weight.

The high speed engine (II, 257) of the Méditerranean line has a direct heating surface of 80,31 square feet; brass tubes 1,81 inch in internal diameter, and 0,08 inch in thickness, giving a surface of 1.190,73 square feet: or in all 1.271 square feet. The volume of the metal per lineal yard is

thus 16,47 cubic inches, and its weight (8,427 being the specific gravity of brass) (*) 5,02 lbs: the length of the tubes is 16,28 feet, and their number 164. Their total weight is thus $5{,}02 \text{ lbs} \times \frac{16{,}28}{3} \times 164 = 2{,}039$ tons. The engine weighs empty 30,85 tons, and full 34,75 tons. The tubes which render the heating surface 16 times greater, only form thus $\frac{1}{15}$ of the weight of the engine empty, and $\frac{1}{17}$ of the engine full; a ratio which applies to new tubes, while their mean state of wear ought to be taken.

It is true that the fire-box is not very spacious, and that the tubes are relatively long, tending to lower their mean evaporative power, which is always very inferior to that of the fire-box (19).

The section of the grate, the number, the diameter, and the length of the tubes should be correlative elements, at least within certain limits; while in reality they are adopted quite arbitrarily, and not even in an empirical manner. At the time when the struggle between the narrow and broad gauges (I, 1) was at its height in England, the heating surface of the Great Western locomotives reached to nearly 2.152 square feet. It was indispensable, at any cost, in the opposite camp, to attain and even surpass this number. This was effected, but by literally cramming the boiler with an infinity of tubes of small diameter, relatively much too long, far too close together, and which took the place of the water and the steam.

These excesses have been given up; but differences are still to be remarked between one line and another, and often on the same line, which could only be explained if advantage was taken of them to make comparative experiments. In spite of the tendency of English engineers to settle down to uniform types, the ratio of the two elements of the heating surface still varies in their engines, about from one to two $\left(\frac{1}{7,3} \text{ to } \frac{1}{15,5}\right)$.

Independently of the condition of a sufficient heating surface, a relation must evidently be established between the diameter and the number of the tubes such that they may present to the products of combustion a large enough outlet; without which it would be necessary to impart an enormous velocity to these gases, which would have the effect of carrying off a very considerable quantity of pieces of fuel, causing a very rapid wear of the tubes, would require a very strong blast, and would consequently produce

(*) This is the number, a little too low for tubes, given by the *Annuaire* of the Bureau des Longitudes, for *brass*.

a notable back pressure on the pistons. While on account of this excessive speed, the gases would be imperfectly deprived of their heat, and the consumption further enhanced.

The only point which at present seems to be agreed on is the diameter of the tubes. Measured inside, it is ordinarily comprised between 1,57 and 1,81 inches, whatever may be their length. It is only rarely for boilers with exceptionally short tubes, such as those of *Mc Connell's* engines (15) and the old twelve wheeled engines of the Northern of France that the lower limit has been passed.

18. *Length of the tubes.* — As to the length, it is still very variable. In some cases it is found as low as 11,48 feet, sometimes as high as 16,40 feet (*Cantal* engine, II, Pls. LVIII to LX) and even as high as 17,58 feet (*Méditerranée* 8 wheeled coupled engine). With such differences the heating surfaces can scarcely be compared. If the tubes are too short, the gases pass off too hot, the fuel is badly utilised, and the temperature in the fire-box which in that case is too high, rapidly destroys it. If they are too long, the heat of the gases is better utilised, but there is a portion, more or less in length which produces very little steam, because the temperature of the gases therein, does not enough exceed that of the boiler; and the length and weight of the engine are increased, without real advantage to the power.

For engines running at low speeds, very often close to the limit of adhesion, these long tubes may be admitted without hesitation, the increase in weight serving to avoid the risk of slipping; but it is well to recall here a distinction already made (II, 378) : admissible for engines intended to draw heavy loads *on flat gradients* at a low speed, an extra load almost inert, nearly equivalent to simple ballast, ought to be rejected for engines working on very steep gradients, because lightness for these is of high importance. Thus tubes of more than 16 feet would be in their place in engines which, like those of the 8 wheels coupled of the Midi Railway, draw very heavy trains on the line from *Toulouse* to *Cette*. They are too long for the *Méditerranée* engines, the principal function of which consists in drawing small gross loads on the gradients of 1 in 40 on the direct line from *Paris* to *Nîmes*, and on the gradients of 1 in 33, on the Mount Cenis line.

Another consideration, deduced like the preceding from locomotives in a state of movement, tends to assign a lower limit to the lengths of the tubes in these engines than in stationary ones. The greater the length of the tubes, the more their vibrations strain their joints, and the more difficult these joints are to keep stanch. Supporting the tubes at their

middle by a plate or diaphragm of iron pierced with holes was tried; but then their bearings on that support rapidly wore away. The remedy was worse than the evil. If it were only the weight of the tubes, there would be no reason for an intermediate support; the stiffness which they owe to their form is such that even the longest, supposed not fixed but simply laid down, on their two ends, deflect only imperceptibly. The deflection has for expression $\frac{5}{384}\, p \frac{a^4}{EI}$; using the same numbers as no. 17, we have: p load on the unit of length or weight *in the water* of a linear yard of the tube = 5,093 lbs. — 3,953 lbs. = 1,140 lbs.; a = 17 feet 1,397 inches; E = nearly 10 millions; $I = \frac{1}{4}\pi\left(\overline{0,98}^4 - \overline{0,91}^4\right) = 0,185\,834$, whence f is hardly $\frac{1}{85}$ of an inch. Absolutely useless at rest, the diaphragm limited the amplitude of the vibrations during running, but by cutting into the tubes.

With long tubes, deep fire-boxes were made overhanging, so as to avoid an excess of wheel-base. The endeavour was thus to render the fire-box shorter, the longer the tubes were, while the contrary should have been done.

"The length of the tubes beyond about 10 feet", says M. *Vuillemin* (*), does not increase the production of steam in a perceptible manner, in *passenger engines.*"

Without dwelling here on this distinction, already criticised (II, 386) and to which we shall return (20), we shall make the remark that the approximate limit of 10 feet only applies of course to the usual dimensions of fire-boxes.

The influence of the length of the tubes on their resistance must also be noted. Mr. *Fairbairn* made long ago, at the request of the Royal Society of *London*, experiments on the resistance of tubes to compression. These experiments, in which the pressure exceeded 400 lbs in the square inch (= 28 atm.), brought out the unfavorable influence of the increase of the length, an influence which is quite naturally explained, were it only by the more numerous chances of flaws, of weak points in the metal, and consequently of deformation. On the other hand by the ferrules the tubes are formed into regular end-stays, the influence of which extends to a certain distance against the tendency to rupture the equilibrium, which is unstable in the case in question. In this respect the suppression of the ferrules may have an objectionable side, but the less so the longer the tubes are.

(*) *De la résistance des trains*, page 71, note C.

The influence of the length in Mr. *Fairbairn's* experiments, is the more readily explainable, as the tubes plunged in the water which was compressing them, were provided at their extremities with plates on which they rested as ordinary tubes do on their rings.

The results of Mr *Fairbairn's* experiments are exactly rendered (*) by the two following empirical formulæ

$$p = 568{,}301\,\frac{e^{2{,}315}}{ld^{1{,}278}}; \qquad p = 24272{,}07\,\frac{e^{2{,}081}}{l^{0{,}564}d^{0{,}889}}$$

where p is the effective pressure in pounds on square inch, e the thickness in inches, l the length, and d the diameter in inches. The first formula suits the most numerous experiments, made on very thin sheets, only 0,043 of an inch in thickness; the second, for a very small number of the experiments, made on plates of from 0,126 to 0,252 in thickness.

19. *Relative evaporative power of the fire-box and the tubes.* — It is to be regretted that regular experiments have not been made to decide a question so important as that of the relation between the two elements of the heating surface. The diameter and the length of the tubes being fixed correlatively, it seems difficult to admit that there would not be an advantage in multiplying them, as much as the space reserved for the steam permits, on the one hand, and on the other, the minimum space necessary for the disengagement of the steam and the facility of cleaning.

However in one of the North London engines (American type), cited farther back (II, 335), the boiler of which is 4,08 feet in diameter, Mr. *Adams* reduced the number of tubes, so that its heating surface was much less than that of the other boilers of the same dimensions. The production of steam, he adds, did not perceptibly vary; unfortunately, the terms of comparison are not put in an explicit manner.

Remarkable experiments made on the Northern of France, confirm, and with much more preciseness, the facts stated by Mr. *Adams*.

These experiments, the most complete that we possess on this important question, were made from 1860 to 1864, by the locomotive department of the Northern of France, the making of them being intrusted M. *Geoffroy*. They present too much interest, not to have their principal results reproduced here; which M. *Delebecque*, chief-engineer, has obligingly enabled me to do.

(*) *Grashof. Die Festigkeitlehre*, p. 244.

The boiler of an *Engerth* goods engine was at first divided by three intermediate tubular plates, into four compartments fed directly by means of reservoirs giving a pressure of a quarter of an atmosphere, which was sufficient, the evaporation varying very little with the pressure. But the first partition from the fire-box alone being pretty stanch, the comparison could only be made upon two lengths, the one including the fire-box (115,71 square feet) and an amount of tubes (75,24 square feet), in all 190,95 square feet; the other, all the rest of the heating surface, or 1159,31 square feet.

Four experiments, made under these conditions, two with coke, and two with coal, gave for the ratio of the gross evaporation per unit of surface, with the first, 17, with the second, 29. The temperature of the gases in the smoke-box varied from 350° F to 400° F.

As the question was especially to ascertain the law of decrease of the evaporative power of the tubes, the boiler of a small *Stephenson* goods engine 210, was set apart in order to carry this program out completely (Pl. I, *fig.* 7 and 8). The cylindrical barrel was divided into four lengths of 2,98 feet, closed by tube-plates and simply placed end to end, the joints *abcd*, *mmnn*, being packed so as to completely prevent any air getting into the tubes. It was wished on this occasion to make the experiments under the normal conditions of working, that is to say, at high pressure; the upper parts of the bases of the sections were consequently strengthened by double angle irons *k*, *k*, *k*, *k*.... Each of them was supplied by a donkey engine. The steam from another boiler produced the draught; and the steam which each of the sections produced, was discharged by valves directly into the open air.

In the first set of experiments all the tubes were open, in the second set, half the tubes were plugged at the fire-box end, and consequently, the tubular heating surface reduced to one-half.

The following tables give the abstract of the results obtained:

1st. Heating surface with all the tubes open..	1st compartment, fire-box.....	76,86	Total..... 794.22 square feet.
	2nd do	179,34	
	3rd do	179,34	
	4th do	179,34	
	5th do	179,34	
2nd. With half the tubes open.....	1st compartment, fire-box.....	68,57	Total..... 426.37 square feet.
	2nd do	89,45	
	3rd do	89,45	
	4th do	89,45	
	5th do	89,45	

TABLE I. — Experiments made with all the tubes of the boiler open.

FUEL employed	VACUUM in the smoke box in inches of water.	FUEL consumed per hour lbs.	QUANTITY OF WATER EVAPORATED BY THE DIVERS COMPARTMENTS. — MEAN OF THE EXPERIMENTS.											
			1st COMPARTMENT fire-box.		2nd COMPARTMENT.		3d COMPARTMENT.		4th COMPARTMENT.		5th COMPARTMENT.		TOTALS	
			Total in gallons.	Per sq. foot.	Total in gallons.	Per sq. foot.	Total in gallons.	Per sq. foot.	Total in gallons.	Per sq. foot.	Total in gallons.	Per sq. foot.	In gallons.	Per sq. foot.
Coke	0,79	436	153,01	1,99	99,57	0,56	41,95	0,36	22,81	0,13	12,80	0,07	331,25	0,45
	1,57	655	201,85	2,63	140,80	0,79	67,10	0,46	37,96	0,21	23,10	0,13	470,80	0,59
	2,36	728	222,20	2,99	178,89	1,00	93,06	0,52	52.80	0,29	33,66	0,19	580,58	0,73
	3,15	794	222,86	2,91	192,06	1,07	99,66	0,56	57,20	0 32	39,60	0,22	611,60	0,77
	3,94	772	181 00	2,36	189,20	1,06	102,96	0,58	61,38	0,34	44,00	0.25	578,60	0,73
General mean.....		677	196,20	2,56	160,90	0,72	81,16	0,73	46,42	0,26	30,62	0,17	514,58	0,65
Block fuel	0,79	476	180,62	2,35	96,36	0,53	42,55	0,25	23,98	0,13	14.74	0,08	360,36	0,59
	1,57	743	2>5,62	3,07	136,84	0,77	73,48	0,41	38,72	0,26	26,40	0,14	511,28	0,65
	2,36	924	293,26	3,82	196,90	0,98	102,52	0,45	64,46	0,36	42,26	0,24	699,82	0,88
	3,15	1,025	329,12	4,30	177,76	1,10	92,96	0,51	57,86	0,39	42,24	0,23	699,16	0,88
	3,94	979	298,10	3,89	249,92	1,39	122,76	0,68	77,44	0,43	50,60	0,28	778,60	1,00
General mean.....		816	267,31	3,48	171,56	0,95	87,05	0,46	52,49	0,29	35,20	0,19	613,80	0,78.

TABLE II. — With half the tubes stopped with plugs in the fire-box.

Block fuel	0,79	388	181,06	2,64	79,30	0,88	35,57	0,40	19,14	0,21	11,66	0,13	327,80	0,78
	1,57	611	205,70	3,00	157,85	1,28	55,00	0,62	30,86	0,35	18,70	0,21	424,05	1,00
	2,36	708	271,00	3,97	144,76	1,62	72,16	0 80	44,88	0,50	29,04	0,32	561,88	1,32
	3,15	794	297,88	4,36	161,92	1,81	84,48	0,94	47,52	0,53	33,44	0,38	625,25	1,45
	3,94	844	305,82	4,47	187,44	2,09	94,82	1,06	57,97	0,66	42,46	0,48	688,60	1,62
General mean		.. ....	252,30	3,69	135,44	1,54	68,38	0,77	40,00	0,45	27,06	0,30	525,49	1,23

TABLE III. — Proportion of water expended by the divers compartments, per cent of whole.

1. EXPERIMENTS MADE WITH ALL THE TUBES OPEN.

Coke	0,79		46,2		30,1		13,0		6,9		3,8		100	
	1,57		42,9		29,9		14,2		8,1		4,9		100	
	2,36		38,3		30,8		16,0		9,1		5,8		100	
	3,15		36,5		31,3		16,3		9,4		6,5		100	
	3,94		31,1		32,5		18,5		10,5		7,4		100	
General mean			39,0		30,9		15,6		8,8		5,7		100	
Block fuel	0,79		50,1		26,7		12,4		6,7		4,1		100	
	1,57		46,1		26,7		14,4		7,6		5,2		100	
	2,36		41,9		28,2		14,5		9,2		6,1		100	
	3,15		47,1		25,4		13,1		8,3		6,1		100	
	3 94		37,3		31,3		15,4		9,7		6,3		100	
General mean			44,6		27,6		13,9		4,8		5,5			

2. EXPERIMENTS MADE WITH HALF THE TUBES PLUGGED.

Block fuel	0,79		55,0		24,5		10,8		5,8		3,5		100	
	1,57		48,5		26,8		13,0		7,2		4,4		100	
	2,36		48,3		25,8		12,8		8,0		5,1		100	
	3,15		47,6		25,9		13,5		7,0		5,3		100	
	3,94		42,2		27,2		13,7		8,4		6,5		100	
General mean			48,8		25,9		12,8		7,3		5,0			

The decrease shown by table I is very rapid; the square foot of the last compartment is only equivalent, with coke, to about $\frac{1}{15}$th of a square foot of the fire-box, and to $\frac{1}{4}$th of the square foot of the first compartment of the tubes; with block fuel, to $\frac{1}{17}$th of the square feet of the fire-box and $\frac{1}{5}$th of the square foot of the first compartment of the tubes. The fire was however, actively kept up, seeing that the evaporation reached with coke 7,71 lbs, and with block fuel 8,8 lbs per square foot mean. Moreover, the depression in the smoke-box went during these experiments as far as 3,93 inches of water, a number it hardly ever reaches when running, and then it varies between 0,79 and 3,15 inches.

Table II brings out the remarkable result, that with block fuel, the suppression of half the tubes has, with an equal depression in the smoke-box, but a slight influence on the total production. The ratio of the complete indirect heating surface to the direct heating surface is however less than 10, that is to say very moderate (17). The fuel besides was at least as well utilised by the reduced heating surface as by the total surface : the pound of block fuel having produced on the average with the first 7,85 lbs, and with the second 7,54 lbs. gross of steam. An absolute result cannot doubtless be deduced from a fact observed in a particular type, but at least it is quite in accordance with the principle so fully established by practice, that the fire-box especially should be made as large as possible, and for block fuel as well as for coke.

The heating surface is thus far from having an absolute signification by itself. We should be in a position to substitute for the gross figures, reduced surfaces which can be compared with each other, referred, for example, to the average square foot of direct heating surface. This is what the Midi Railway has tried to do for its types of engine (II, 394). This method, which consists in neglecting all that exceeds 13 feet in length and applying to the surface thus reduced the coefficient $\frac{1}{3}$, is exact enough perhaps, as long as the ratio of the tube and direct surfaces is pretty constant; but we see by the experiments of the Northern of France, to what errors it would lead if this ratio varies much, on account of the variation in the number of tubes of the same diameter and the same length.

If the suppression of a certain number of tubes affected neither the power of the engine, nor the useful effect of the fuel, it should be carried out without hesitation. As to weight of metal, the gain would be slight; but

the reduction in the number of joints, and consequently in the chances of leakage, the less encumbering of the cylindrical barrel, the increase in the volume of water, the easier disengagement of the steam, are not advantages to be despised. It would be easy to carry this part of the experiments of the Northern of France into the current service, by running an engine during periods long enough for the consumption to be exactly verified, with the tubes plugged on the side of the smoke-box and successively increasing in number: conditions less favorable than those where the tubes of an engine are regularly suppressed.

Evaporation was often very violent, particularly in the first compartment of the tubes, in which the ratio of the water contained to the steam produced was smaller still than in the fire-box. The water thus escaped abundantly through the valves and so gave wrong results.

According to Mr *Armstrong* (*) the production of steam from the roof of the fire-box is double that of the sides; which would be that the steam formed on the latter, passing off vertically, tends to keep the water away from them.

If the fact and the explanation are correct, it would be desirable to give the sides of the fire-box a certain slant. The slight reduction in the roof which would result therefrom, would be far more than compensated by the greater facility given to the steam to pass off, and consequently to the access of the water to these surfaces. This inequality of production ought to apply still more to the tubes. The upper half ought to give more steam than the lower half, the disengagement of the steam which the latter produces being hindered by the tube itself. Carrying over water mechanically, which is the more marked the more active the evaporation, necessarily exaggerates the superiority of the gross production of the direct surfaces. We shall return to this fact of the mechanical carrying over of water, its measure (38), and, farther on, its consequences.

20. *Mean power of evaporation. — Influence attributed to the velocity of translation.* — The mean power of evaporation per unit of surface is very considerable, especially in engines with large fire-box and with tubes neither too long nor too numerous. The mechanical work available on the driving shaft, referred to the square foot of heating surface, is itself relatively considerable, in spite of the imperfection of the motive apparatus, an imper-

(*) *Clark*, page 126.

fection inseparable from non-condensation, but, at the same time, less than is often believed.

The boiler fulfils in a satisfactory degree these two main conditions: complete combustion of the fuel, and transmission to the water of the heat produced. As far back as 1853, MM. *Ebelmen* and *Sauvage* had already shown by some experiments, which were unfortunately not continued long enough, that the proportions of carbonic acid, carbonic oxide, and oxygen, were, the first greater, the two others smaller in the products of combustion from locomotives, than in the gases coming from ordinary stationary boilers. At that time however, coke was used; it was only when the depth of fuel on the grate was excessive and the blast weak, that the proportion of carbonic oxide became notable. The slight thickness of the metal plates is besides very favorable to the transmission of heat, especially when the water is pure and the incrustation slight.

To establish the influence attributed to the velocity of translation (a point already touched on, II, 386), M. *Vuillemin* and his coadjutors quote first the following numbers (*):

Crampton.....	at 2,83	turns per second,	8,6	lbs per square foot per hour.
Mixed engine.....	at 2,77	do	7,7	do

These differences are evidently too slight to warrant any deduction being drawn from them.

"In general", continues M. *Vuillemin* (**), "for goods engines, the production per square foot of heating surface and per hour, is less than for passenger engines; for engines with four axles coupled, running at full power, this production was only from 3,3 to 3,7 lbs.

"These engines ran very slowly, and the draught was slight.

"The engine with 4,27 ft wheels, running at 23 miles an hour gave 6,5 lbs.

"The engine, type 20, running at full power, as to adhesion, gave a production of 4,1 lbs; the same engine running at full power, as regards production, gave 6,0 lbs at 15 miles an hour."

The numbers admitted are:

On the *Orléans* system :	miles an hour	per sq. ft. H. S.
Passenger engines.....	from 23 to 28	6,1 lbs
do do.....	43	7,7
Goods do.....	15	5,1 to 5,3
On the Northern of France, *Crampton*	47	10,2

"Thus", conclude the engineers of the Eastern of France (***), "the faster an engine

(*) *De la résistance des trains*, etc., page 71.
(**) do page 76.
(***) do id.

runs, the more *steam* it produces per hour, and per square foot of heating surface; *consequently*, the more *work* it can produce. From the point of view of production, there is thus an interest in pushing the velocity up to the limit which could not be exceeded without straining the machinery. "

Against this assertion, as to what concerns the production of *steam*, it is sufficient to put : 1st, the example of the Mediterranean lines (II, 386), where the evaporation prescribed and carried into effect, is uniformly 8,2 lbs. and by exception, 7,2 lbs. for engines with 8 wheels coupled, on account of the length of their tubes; 2nd, that of the six wheels coupled engine of the Upper Italy lines, which run 9 miles an hour up the *Mount Cenis* inclines, producing 9,2 lbs. per square foot (II, 450); 3rd. that of the *Semmering* engines, in which the production reaches the same figure; 4th. that of the Eastern of France engine with driving-tender, which produces, according to M. *Vuillemin* (II, 401) 10,2 lbs., running at 11 miles an hour, and even according to M. *Jacqmin* (*) up to 12,4 lbs. per sq. ft., running up the gradients of one in 40, on the line from *Spa* to *Luxembourg*. While quite appearing to share M. *Vuillemin's* opinion in what regards the pretended *necessary* influence of the speed, M. *Jacqmin* adds however (**) :

" In all cases, we believe that the quantity of water evaporated in an hour by each square foot of the heating surface of a locomotive of ordinary dimensions may be without objection estimated at from 7,2 to 8,2 lbs. "

It is precisely in the low speed engines, that this number of 8,2 lbs. is oftenest exceeded.

If an engine does produce more *work* the faster it runs, this is in no way because it produces by that very fact " more *steam* ", as the first quoted work states, but simply because, with equal evaporation (and if desired it is so), the admission is reduced, and the expansion increases with the speed, and the steam is thus better utilised. We shall return however to this main point, when treating the subject of the dimensions of the cylinders.

21. *Measure of the total heating surface.* — It is not without use to point out a want of uniformity in the mode of calculating the indirect heating surface. This term refers to the inside surface of the tubes, as it is that which is in contact with the hot gases. It is often however, the outside surface which is given; and with reference to engines with tubes of 1,8 inches external diameter and 0,08 inch thickness, this mode of estimating exagge-

(*) *Des machines à vapeur*, vol. II, page 269.
(**) do do do.

rates the real surface by nearly 9 per cent. It is thus necessary before establishing comparisons between heating surfaces, to make sure that they have been calculated in the same way. Sometimes it is the mean diameter which is taken. It matters little which mode, provided the same be always adopted.

22. — *Details of the arrangements of the tubes.* — The tubes introduce hundreds of joints into the boiler; which can only be made stanch by somewhat minute precautions, the importance of which does not allow them to be passed by in silence. The tubes may be placed, either zig-zag, or in vertical rows; the first arrangement was long preferred (II, Pl. XXI, *fig.* 2; XXXIII, *fig.* 2; XL, XLI, *figs.* 2 and 3; XLII, *fig.* 2; LXII, *fig.* 2; LXXVI, *fig.* 3, etc.); nowadays the second is general (Pl. XXII, *figs.* 2 and 3; XXVII, XXXII, XXXVII, *figs.* 2 and 3; XLIII, *fig.*2; XLVI, *fig.* 2; LII, LVI, LVII; *fig.* 2; LV, *figs.* 1 and 2; LXVIII, *figs.* 2 and 3); it facilitates the action of the scraper (which often puts off the extraction of the tubes), as well as the disengagement of the steam.

For an external diameter of 2 inches, it is desirable that the space between centres should not be less than 2,56 inches which leaves a clear space between the tubes of 0,59 inch, hardly sufficient when the tubes are long. It diminishes, in effect, at certains points, while it increases in others, on account of the tubes going out of shape, and it thus sometimes becomes small enough to be blocked up by tartar. At times even, the tubes get so close as to touch each other; and they then wear out rapidly by rubbing against each other. It is to reduce these drawbacks that the intermediate supports (18) are sometimes had recourse to, their thickness being increased to diminish the wear; but it is far preferable to increase the distance between the tubes a little.

Tubes bent out of shape downwards, are less stiff, and exercise a less thrust on the tube-plates than straight tubes. In some engines on the *Stockton* and *Darlington* line, they tried applying this deformation systematically; all the tubes had a double bend towards the smoke-box, but the arrangement renders it more difficult to take them out.

The tubes are generally brass. When made of iron, they become rapidly corroded inside, unless very pure coal, wood, or turf is used; and experience proves that on the outside, the deposits adhere much more to iron than to brass : an objection which vanishes of course, when the water is pure and therefore does not deposit. With iron it is difficult to make good joints; but at the same time, expanding less than brass, it strains the tube plates

less by its thrust. The choice is altogether a question of fuel, and above every thing a question of *water;* oftenest decided in favor of brass, it may be so in certain cases in favor of iron. It is for example very much used in the United States, but with copper ends brazed on next the fire-box.

The trial of iron tubes is of old date, even in France. The first engines constructed by M. *Koechlin* for the line from *Lyons* to *Geneva*, had iron tubes, also with copper ends.

On the line from *Cologne* to *Minden*, the trial of iron tubes kept pace with that of iron fire-boxes. They have been given up, on account of the frequent leaks and the adherence of deposits.

Some German railways have kept to iron tubes, and found advantage therein; others after having given up the same, have returned there to.

Replacing the worn end of a tube by a fresh piece, can be done with iron tubes as well as with brass ones. On some lines, this operation is done by taking advantage of the characteristic property of iron, that is to say welding the piece on at a high temperature; but brazing is more simple and is sufficient. Tubes of cast steel got by drawing out a ring were manufactured as far back as 1863, but their high price prevented their adoption.

Bessemer steel has more recently been the object of some trials, which however do not seem yet to be conclusive.

It may be asked why the tubes are not of copper like the fire-box, although, however, they are frequently enough so in the United-States. In the first place, brass is not so dear; but what is particularly sought after is a certain degree of hardness, by which the tubes resist, better than copper, the friction of the solid particles carried over by the gaseous current.

However, as we have just said, and we shall return just now to this detail, no fear is felt in employing copper partially, it is true, but precisely for the portion most exposed to that wear, that is to say, at the point of insertion into the fire-box. The malleability of this metal allows better joints to be made; and the more rapid wear may besides be compensated for by an extra thickness at that part.

Brass contains generally 0,32 of zinc; for economy's sake, it has been endeavoured, to raise this proportion to 0,60; but the alloy was then too brittle, and the former proportion, or very nearly so, had to be come back to. The Upper Italy Railway, even lowers the amount of zinc to 0,30, and the Belgian State Railways to 0,25. Lap-welded tubes are now altogether given up; and nowadays only drawn tubes are employed.

The tubes being necessarily introduced and extracted through the door of the smoke-box, the holes of the front tube plate should be a little larger

than those in the fire-box plate, so much the more so as the tubes to be taken off, either for replacing, or for scouring or repairing, have their diameters more or less increased by deposits of tartar.

The difference often amounts to 0,12 inch; for example, for tubes 2 inches in diameter (externally) the front holes are 2,04 inch and the others 1,92 inch. The hinder ends of the tubes should then be gradually reduced 0,079 inch and their front ends enlarged 0,039 inch. The first operation is done of course before fixing, and the second when the tube is in place. For a copper plate 0,98 inch thick, the tube should project 0,20 of an inch into the fire-box, for the formation of the flange; the conical tapering applies to a length of 1,18 inch, which is easily done (*) by driving the tube sharply, with one blow, and exactly along its axis, into a cast iron mould 1,89 inch in diameter at the bottom. The enlargement of 0,039 inch at the other end of the tube, is obtained by means of a slightly tapering conical mandrel. The flanges are formed by means of a special tool (Pl. I, *fig.* 9) provided with a cupped projection *e* which successively turns the metal over.

Sometimes the tubes slightly decrease in thickness from the fire-box to the smoke-box, to make up for the wear which takes place in the same direction. Example : *Cantal* (*Orléans*); *l'Avenir* engine (II, 363 and Pl. LXXX). The tubes 15,82 feet between the plates, and 2 inches in external diameter, have a variable thickness from 0,10 in. to 0,069; but this shape has been given up. Workmen did not take the taper into account, and the tubes being put in at random, were often fixed with the thin end next to the fire-box.

23. *Rings or Ferrules.* — In France and England, the closing of the joints is ordinarily done at each end (II, Pl. XXXIX, XLI, etc.) by means of a regular wedge, that is to say a ring or thimble, conical on the outside, chamfered a little so as not to split the tube, and as thin as possible, so as not to reduce the air section. These rings are of iron or steel, 0,079 inch in thickness and 1,38 inch in length. After being put in place, they ought to project slightly about $\frac{1}{5}$th of an inch, in order that they may be afterwards driven in a little farther if required. There are of course two types, when the diameter of the tubes is not the same at both ends. They ought to be driven home with precaution by means of a drift (Pl. I, *fig.* 10). It is as well to put a few tubes in at first here and there, so as to keep the

(*) *Petzholdt. Fabrikation, Prüfung*, etc., p. 87.

plates up, and only to drive the ferrules home when all the tubes are in their places.

Not being as directly cooled by the water as the plate and the tubes are, the ferrule becomes tighter, higher the temperature. Thus it is often remarked that leaks which show themselves when the fire is lighted cease when the pressure rises. This fact, to which the obstruction by the solid matters deposited by the water may also contribute in a certain degree, is a useful property of this method of fixing. The ferrule also protects the part of the tube within the plate, a part which if uncovered, rapidly burns; this protection is however at its own expense, which of course is a small matter.

The high temperature existing in the fire-box, and the strains to which the tube-plate is often subjected, render caulking more difficult at this end of the tubes than at the other. Thus the ferrules in the fire-box are often longer than those in the smoke-box (II, Pl. L, Spain; Pl. LVI, *Ceinture Koechlin*).

In Germany, putting ferrules in at that end has been given up long since. In France, it is however pretty frequent, on the Northern for example (II, Pl. XXX); but it has not yet become general. In some of the Western France engines (Pl. XXXIV) it has been combined with a detail taken from some German lines : a little projection or rather circular flange knocked up in the tube, which thus takes the plate between the flange and the turned over edge.

In Germany the ferrules are objected to, because besides the evident disadvantage of the reduction of the opening, they strain the tube plate more, and contribute to the formation of cracks. Thus some builders do away with these rings altogether, not only in the smoke-box, but even in the fire-box (a thing by the way already done, it may be said from the outset, in engines burning turf). In that case they add to the fire-box end of the tube a copper portion of from 4,33 to 5,12 inches which the tapered and countersunk tube is set in and brazed on (Pl. I, *fig*, 11). Drifting the copper end, which is more ductile than the brass, and thicker besides, is sufficient to make a tight joint. The Austrian North-Western applies this method to iron tubes, and as stated, with great success.

Screwing the brass tubes into the copper plate has been tried also, but this costly and delicate process renders their extraction very difficult. Sometimes also, for the inside ferrule, a thinner ring in copper is substituted, brazed on the outside of the tube that it takes; a slight continuation of this ring, turned over the end of the tube prevents it burning so rapidly.

M. *Krauss* keeps the separate copper end (II, Pl. XXI, *fig.* 1) and he throttles it at the extremity *b* in such a way that the tube plate is let in for its whole

length into a sort of groove. At the other end on the contrary, at *e*, the tube is widened out, so that the large diameter of the hole facilitates the extraction of the tube. Most of the German lines are now quite agreed as to the complete suppression of the rings, keeping the brass tubes, but with a copper piece brazed on, at the fire-box end.

In some English engines, suppressing the ferrules at the two ends, has been also tried. At the fire-box end, the tube has an extra thickness on the part let into the plate; on the other side it is of the regular thickness, but is turned down to the external diameter of the other end (Pl. I, *fig.* 12). In all cases the tube must be carefully mandreled so that the tube may exactly fit the hole.

The Upper Italy lines have recently received engines, some with ordinary tubes and ferrules in the fire-box, others without ferrules, with tubes having copper ends; the former locomotive engineer, M. *Pelletier*, could not, he said, yet give an opinion as to the value of these trials; he called to mind the failure of those of the Alsace Railway in 1848; the tubes rapidly deteriorated at their entrance into the fire-box plate; as to the copper ends, M. *Pelletier* feared that failures at the weld may notably reduce the ordinary durability of the tubes.

Perhaps the moment has not yet come for suppressing the ferrules, while pressures are being raised. However, if stanch joints can be had without them, there is an end of the matter. Some engineers think it is necessary to drive in the ferrules with great force, in order that the tubes may act as stays to the two tube-plates. But these two plane surfaces in no way require to be stayed at the part where holes are; and in any case, tubes do not appear to be in the least suitable for this purpose; they cannot be assimilated to *solid* tie-rods, placed in the water, and having the same temperature; in reality, far from staying the tube-plates, the tubes on the contrary bring a considerable strain on to these plates by the thrust due to the excess of their expansion over that of the body of the boiler; the tube-plate in copper tends to bulge out towards the fire-box; an effect which is increased by the pernicious practice, which is at last being given up (33), of making it support the roof. If it were possible to combine the absence of leakage of the joints with a certain faculty of relative sliding, at least at one end, everything would be right.

Enlarging or throttling the ends of the tubes is a complication, which however reduces their longitudinal stiffness, and consequently, their thrust on the plates; the variations of length can be compensated for by a variation of the junction curvature where sections change.

24. *Plugging the tubes.* — The crushing in of the tubes occurs pretty frequently, but the consequences are confined to a simple stoppage. If the tube is completely broken, the boiler gets emptied, and the water puts the fire out. The driver can sometimes avoid a stoppage by driving an iron plug in with care in the fire-box, and a wooden plug in the smoke-box; the water simply takes the place of the tube. A wooden plug may indeed suffice also in the fire-box; the leakage protects it against burning, and so allow a station, if not the engine-house, to be reached. Engines used to be seen on small lines, where maintenance was made at leisure, which had been running for a long time with their heating surface reduced by the plugging of several tubes; a state of affairs which by the way did not reduce their power as much as would have been thought (19).

But what was easy formerly, is less so with existing engines with large fire-boxes, high pressure and tubes of greater diameter. Not that the elevation of the normal pressure renders putting in the plug more difficult; the pressure very rapidly lowers by the very fact of the breaking of the tube, but the plug would resist with greater difficulty, once the pressure got up again, so that the driver properly ought not to attempt the operation, unless the gradients and the load will allow him to get to the next station with reduced pressure. This condition is the more necessary, as the driver and stoker may be seriously wounded, as has been known to occur by the flying out of a plug, if it should happen while they have the door open for stoking. In fact, three out of four times, with passenger trains, the driver ought to avoid plugging, and the breakage of a tube amounts to a stoppage; as to goods trains, for which a lengthened delay is of less importance, the driver can sometimes shunt, let his fire down, and partly empty the boiler, plug the tube, fill up again if there is enough water in the tender, light up his fire again, get up steam and go on.

Plugging is besides also sometimes applied to stop a simple leak when the escape of water is too great.

The partisans of copper ends without ferrules, admit also that this arrangement absolutely excludes plugging, as the copper being too ductile is unable to protect the tube-plate sufficiently against the violent action of the plugging; but they attach little consequence to this, as the operation seems to them to be little valuable by itself.

25. *Assortment of tubes.* — Nowadays, all the tubes of an engine are kept as far as is possible in a state of *equal resistance*, so that all the elements reach their limit of wear about the same time. On the Eastern

of France, for example, the matter is thus regulated (art. 63 of General Order No. 5, locomotive department) :

" The tubes are divided into three categories, according to their degree of thickness.

" The first includes new tubes, and those which have run a distance of 37,300 miles at most, and weigh 5,36 lbs. to the yard and over.

" The second includes tubes which having already run 37.300 miles continue their service up to 64.700 miles and weigh from 4,43 lbs. to 5,36 lbs. to the yard.

" The third is composed of tubes having run 64.700 miles, and weigh from 3,66 lbs to 5,36 lbs. per yard."

Article 205 of General Order No. 7 states :

" Each engine-book contains a sketch representing the tube-plates with the numbers of the tubes. Whenever a tube is to be changed, the foreman ought, in the repairing book, to note the number of the tube according to this sketch and the category of the replacing tube. They ought always to be of the same category. "

On the Eastern of France, the repairing and the cleaning of the tubes are centralised in the *Epernay* shops, where all the tubes taken out in the different engine-houses are immediately sent. On each of them is marked in a prominent manner the number of the category to which it belongs. The damaged tubes are replaced by others of the same thickness and all those of the same engine arrive nearly at the same time at their last limit of wear. With water of average quality a good set of brass tubes is stated ordinarily to run from 111.800 to 124.300 miles ; but it is wrong to measure the service of the tubes by the distance run, to which it is only proportional for engines doing the same work. Everything else being equal, the distance run by a set of tubes is much greater in passenger engines than in goods engines, for the very simple reason that the wear is a function of the time, and not of the distance run.

26. *False tubes.* — In order to multiply the means of cleaning boilers, a certain number of tubes of the lower rows are sometimes suppressed, and the corresponding holes closed by screw-plugs, called *washing-out* plugs. But, in the fire-box, the projecting square head of these screws rapidly became destroyed. Closing up the opening on that side has been tried by a thin surface pretty far away from the fire. Such was the object of the *false tubes*, pieces of tube terminated by a disc brazed on, withdrawn by the length of the piece (about 8 inches) from too near an action of the fire (Pl. I, *fig.* 13). With actual pressures, *false tubes*, kept in place only by the tightening of the ferrule, should be proscribed ; they may, like the plugs, be the cause of accident. Upon the Eastern of France, a false tube was blown out while the driver was attending to the fire; and he was seriously injured,

not by the piece of tube itself, but by the water and steam. To close up a tube-hole, there is nothing better than screwing in a copper plug flush with the tube plate. Nowadays, there are no washing-out plugs for the cylindrical barrel, excepting in the front plate (II, Pl. XXI; XXIII; XXX; XXXIV; XXXIX; etc.).

27. *Extraction of the tubes.* — Scales often render this operation difficult, and very injurious to the tubes and the plates. Different tools may be made use of. For example, after having cut out the ferrules, and raised or cut off the flange at the fire-box end, a conical shank is let at the other end of the tube (Pl. I, *fig.* 13) with a hook of the small end by means of which it is pulled. Between the tube and the shank, a ring in two halves, *b*, *b*, is let in placed against the hook when the shank is full in, and which acts as a wedge when the shank is pulled. The tube is thus taken along by friction, who increases with the strength of the pull.

After extraction, the stroke of a hammer on the hook, drives the shank in and sets the ring free. The latter ought to have a certain length in order to spread the pressure over a sufficient surface; otherwise the tube would give way. This apparatus is analogous to the ram's tongue used for lifting dressed stones.

The resistance to getting a tube out is at times pretty considerable, especially for iron tubes, and in that case a locomotive is hooked on.

A simple enough method and sometimes in reality the least injurious to the tube, consists in driving it first an inch or so into the fire-box, cutting off the piece which sticks out, then pushing the tube back towards the front; as soon as it leaves the fire-box plate, it falls into the body of the boiler, whence it is withdrawn by the man hole, or other opening. This process is scarcely practicable however, unless the whole or nearly the whole of the tubes extracted are to be; for isolated tubes could with difficulty be extracted from the middle of the lot. However the assortiment of the tubes in categories of weight (25) would generally require all the tubes to be replaced at the same time.

Whatever may be the mode practised, the ends of the tubes are always damaged for an inch or two, and they cannot be brought up to their primitive length, excepting by a piece put on. The stock of the same line including different lengths of boiler, it is sufficient, to avoid this operation to pass the shortened tube into another class of a shorter length. This is an argument in favor of uniformity of diameter, whatever may be the length of the tubes.

When a tube is taken out, it is not rejected unless it has arrived nearly throughout its whole length pretty close to the limit of wear. If it is only damaged locally at the part next to the fire-box, the damaged end is cut off, and replaced by a piece cut out of a tube generally defective but with sound portions.

28. *Scouring of the tubes.* — The scouring is done either by solution in a bath of hot water acidulated with hydrochloric acid, or mechanically in a sort of cask. Solution, which was much used in France formerly, but less so nowadays, is done in a wooden trough lined with lead. The tubes when clean are well washed in pure water; but the metal is attacked, both copper and zinc being found in the trough. For iron, the acid ought to be less diluted than for brass, and repeated washing is necessary also after immersion, without which oxidation would rapidly take place.

The tubes can only be handled by means of tongs; and the vapours render the workshop unwholesome. Mechanical action is thus preferred. The tubes are cleaned in that case: either 1st, by their mutual friction; or 2nd, by this friction joined to the action of a certain quantity of iron turnings, or simply gravel; or 3d, by the second action alone.

In the two first cases the cask, formed of pine staves, hooped with iron, is closed by two cast iron plates provided with openings for putting in and taking out of the tubes, to the number of 20 or 25. The operation may be done with water, or dry, and with or without the addition of the turnings or gravel, according as the reactions of the tubes are sufficient or not to detach the scales. In all cases, water greatly hastens the operation.

In the third case the cask has internal partitions pierced with holes, each of which takes a tube. Separate plates close the ends. The tubes not acting in that case one upon the other, a cleansing body is necessary: ordinarily siliceous gravel; water is filled in and shaking done. This method is applied on the *Orleans* line.

The friction of the tubes aided by the energetic action of the turnings, is especially suitable for iron tubes; the adhesion of scale being much greater with iron than with brass.

Another means of *mechanical scouring*, suggested by the use of the tools which serve to rough (*fraiser*) the portions to be brazed, and to turn them afterwards, has been tried in Germany. It consists in letting one end of the tube into a sort of chuck formed with four radial jaws pressed by springs, and which receives a rotatory movement, while the workman pushes the ube on lengthways. The position of the four scrapers is regulated so that,

when free, they correspond exactly to the external diameter of the tube. To disengage the tube, the scrapers are loosened by means of a key.

29. *Distribution of volume between the water and the steam.* — This varies much. With four inches of water above the roof of the fire-box the ratio of the volume of water to the volume of steam goes sometimes up to 4,1 (engines with six uncoupled wheels, series 16, Northern of France); while in others cases it goes down to 1,35 (engines with four coupled wheels of the same line). Nowadays it more often oscillates about 2.

§ IV. — Stays.

30. The cylindrical barrel, of circular section, is the only part of the boiler which does not require stays, against the internal pressure. If it be wished to raise this pressure, the diameter is increased, the real stays being an increase of thickness since the metal works nearly uniformly in extension (5). The length has however, a certain influence, much less marked than when acted on externally (18); the resistance increases if this length is reduced, which can be done by dividing the shell into sections by means of rings, and this is done quite simply by the cross rivetting, either of a lap-joint, or covering-plate. But the effect of this local increase of thickness is not as net as that of a uniform increase, and if we apply it at the joints, although it is a guarantee the more, in what proportion is of course not known.

Remark on the resistance of a very thick cylinder to an internal pressure, and to an external pressure. Against an external pressure, cylinders often require stays; the instability of equilibrium is thus met at less cost than by extra thickness, which would sometimes have to be very considerable.

Without dwelling here on a point which does not apply to locomotive boilers, we may however, note a fact which perhaps has not been remarked. If a very great thickness as compared to the internal diameter, is rendered necessary by the amount of the pressure, this circumstance, so unfavorable to the action of the metal in the case of an internal pressure (5), on the contrary improves its conditions much, in the case of an external pressure. As soon as the thickness is great enough to render deformation, that is to say the bending impossible, the metal works only in compression. For iron, for steel (I, 361), and for cast iron especially, the resistance to crushing is greater, and often much greater, than the resistance in the opposite way;

the pressure per unit of surface, on its periphery, which a very thick cylinder can resist, is thus more considerable if applied externally, than if it acts inside.

Plane faces of the outside shell and inside box. As to plane faces, subjected to bending strains, it is only with excessive thickness that they could resist thereto by themselves; and, independently of other draw-backs, those which are in contact with the fire would be very rapidly attacked. The principle applied wherever parallel plane sides are dealt with, consists in joining them together by ties, creating fixed points near enough together, so that in the intervals the plates may suffice in themselves. This principle applies the better to the vertical faces (except often, as we have seen (4), a slight curve towards the top) of the inside box and outside shell, the nearer they are together, so that the ties or stays may be multiplied without exaggerating the cost and the weight. Besides, their multiplicity results necessarily, as we shall see just now (33), in a great number of engines, from a consideration independent of the direct pressure of the steam on the two opposite faces.

Stays are ordinarily from 0,86 to 0,90 inch in diameter, and are 4,13 inches apart at the most. In the Upper Italy engines, their distance apart is 3,58 inches vertically and 3,50 inches horizontally. They are almost always of copper, and not of iron; a necessity which is often stated to arise from the nature of the fire-box, the contact of the different metals exerting it is supposed, at the high temperature existing in the fire-box, a certain influence on the destruction of iron stays. It is true that the effects of this contact are translated on the iron plates of the outside shell; and the erosions which are developed in the latter, round the stays, are probably due in part to this cause (and also to the action of the punch, which renders iron more easily attacked by water); but at any rate, the temperature under the influence of which the first acts is in that case much less elevated.

A more real and sufficient ground for the preference given to copper, is the necessity of screwing, which is always indispensable, especially for iron, which burns more rapidly, and the inside head of which would be sooner eaten away. When the head does not resist sufficiently, the stay still holds on by the screwing. But this evidently excludes rivetting hot; and in order that the head may be shaped cold without cracks or splits, the iron must be of very great ductility, but which scarcely ever reaches that of good copper, much less resisting it is true however; it does not support more than 15 tons on the square inch, without lengthening 20 per-cent (43).

The axes of the holes ought to be exactly on the same normal to the two faces to be connected. When that condition is not fulfilled, it is necessary

to enlarge the holes, centering them exactly, and then put in thicker stays.

When the heads are eaten away in the fire-box, a hole can be pierced therein, as has been done on the line from *Frankfort* to *Hanau*, of a depth equal to the thickness of the tube-plate, and driving in little steel wedges. This wedging up does not exclude boring (31); but the stays in that case can only be removed from the outside.

31. *Bored stays.* — When a stay breaks, its contingent of tension is brought upon its neighbours, and these may then with greater reason, give way in their turn : an explosion being imminent if a certain extent of the flat side becomes thus deprived of stays. The narrow water-spaces round the fire-box being difficult of access, the state of the stays can only be verified from the outside; in the shops the over-seers used to try to ascertain the existence of solutions of continuity by the nature of the sound obtained on striking the heads with a hammer; but this was a very insufficient means. There is however, a perfectly certain one, which has long been applied in England, and which is spreading everywhere : the longitudinal boring of the stays.

If they have to be bored here and there, the copper rods to be cut off in lengths are previously bored by means of a very simple drill, giving perfectly centered holes.

In the first stays of this kind adopted on the *Méditerranée* lines, the holes were only 0,079 inch in diameter; when carried to 0,158 inch, it was still found insufficient and then carried to 0,276 inch. All those which had holes of a smaller diameter were withdrawn from the stores and their holes enlarged, in spite of the slight loss of resistance which results therefrom.

It is clear that the rivetting once done, the opening must be closed either in the outside or in the inside head; otherwise each stay would send into the fire a small jet of air, and these hundreds of jets, good up to a certain point, but only after charging the fire, from the point of view of smoke consumption, would involve serious drawbacks, among others an increase in the consumption of fuel. When a stay breaks, the water runs out of the boiler and either rushes outside or into the fire-box. In either case the driver is warned; if the opening is to the outside, the wooden sheathing, or in sheet iron cleading which is better (86) for preventing the cooling of the boiler, hides the stays. A cloud escaping from the sheathing advises the driver of the fact of the breakage, but without showing him exactly where it occurs, which however is not necessary. It is only in

the engine-house that the exact position can be ascertained. It is on this account desirable that the plates of the sheathing of the fire-box should be put together by screws and easily taken down. In some German engines, the point of the leakage is made visible; to each of the heads corresponds in the sheathing a hole which receives a ring *b* (Pl. I, *fig.* 14); a great deal of complication for a very trifling result. The leakage into the fire-box is ordinarily preferred, more especially as the first thing a driver has to do when a stay breaks, is to throw down his fire, unless he is quite near a station. On the *Cologne* and *Minden* Railway, closing the opening on the inside head has been adopted, so that the driver may then, strictly speaking, avoid throwing down his fire, on condition of keeping his pressure as low as possible, which is evidently an indispensable measure of prudence. It was besides considered that on this side, the closing would be effected, at least at the lower part by the introduction of ashes and clinker. The diameter of the holes is only 0,12 inch; but it seems sufficient.

On many lines, on the *Orleans* system among others, the stays are only bored towards the extremities; the body remains solid. The result is the same, experience proving that fracture always takes place towards the extremities; but then the two openings remaining free, the water is sent out either outside, or into the fire-box, according to the side on which the fracture takes place.

Often enough indeed, the stay is only bored in the end next the fire-box: in the engines of the North-Eastern of Switzerland it is so. The stays, one inch in diameter, are bored at one end with a hole of 0,12 inch. The body of the stay is turned before being is put in place, so as to completely remove the screwing; not even a single thread is allowed between the plates.

This thinning of the body does not affect the resistance of the stay; it simply removes the apparent excess of resistance to extension of the *body*, over the resistance to the shearing of the threads entering into the plates, and it has the advantage of increasing the flexibility of the solid and of thus reducing the strain corresponding to a given deflection. And even when the angle of the thread is too sharp, the turning down by removing every trace of screwing increases both the resistance to extension and final elongation, because the inside angles act as a commencement of fracture.

These stays with enlarged ends are a good deal used in England.

The localisation of fracture towards the extremities proves that the stays are not subjected only to a uniform effort of extension, and that flexion comes in.

This results, in effect, from the inequality of the expansions and con-

tractions of the two connected sides, which inequality is greater because the more dilatable is at the same time that which is heated the most.

The lower frame being a fixed base, common to both, the deflection of a stay is evidently proportional, every thing else being the same, to its distance from that frame.

Experience proves in effect that fractures are considerably more frequent in the upper rows, at least for the two side faces.

As to the cross faces the hind one has, towards the top, another fixed portion, that which is circumscribed by the frame of the door; and the front plate is occupied, not by the stays, but by the tubes.

As these latter must not be too near the bottom of the barrel, there remains below them a portion of the tube-plate which it is well to tie to the side of the barrel. The best means consist in rivetting on to the latter a hook, which is applied by its widened extremity to the copper side, to which it is fastened by a stout screw (II, Pl. XXXIV, *fig.* 1) and sometimes by rivetting (Pl. XXXIX).

32. *Continuation of the front and hind surfaces above the level of the fire-box.* — There still remain two portions of plane and parallel surfaces to stay, that is to say the upper portions of the hind face of the inside box, and of the tube-plate. Formerly, the same principle was also applied, in this case and always under the same form.

One or two rows of T iron rivetted on these faces were connected by long tie-rods, taking the web of the T with their ends forked out, and the strain on which was regulated by keys (II, Pl. LVIII). These rods, then more numerous, and of less section, were also, and are at times still applied directly to the sides to be stayed, replacing the keys, by screws, which are much preferable for regulating the strain (II, Pl. XXIII, *fig.* 1, 2, 3, τ, τ).

These long tie-rods, heavy, cumbersome, inconvenient for the inspection of the boiler, and for breaking off the scales, have very nearly disappeared. Although differing in their details, the arrangements in use at the present day are always founded on the use of the barrel itself as a tie-rod.

The opposite plane faces are strengthened either by T irons, or by angle irons alone (II, Pl. L, *u*, *u*) or attached to a very projecting web (Pl. XXX), or by U irons (Pl. XXI, *fig.* 1, A, A).

These pieces, forming one or two rows, according to the height to be stayed (II, Pl. XXXIX, *u*, *u*, *u*; Pl. XLI; Pl. L and LII, *u*, *u*; Pl. LVI; Pl. LXVI), are hooked directly on by their extremities to the sides of the fire-box or two thick divergent tie-rods are anchored on to the shell; a method especially

suitable for boilers which present an abrupt change between the fire-box and the barrel; thus it is only applied on the side of the fire-box, and not on the side of the smoke-box (II, Pl. XXXIV, θ, θ; Pl. XLIV, τ, τ; Pl. LXXVII).

Sometimes (Northern of Austria, etc.) gussets rivetted g, g (Pl. II, *fig.* 2), connect the hind side of the fire-box to the cylindrical barrel.

33. *Fire-box roof.* — For the fire-box roof, a plane side opposite to a curved one, the method of stiffening by stays loses much of its advantage. On the one hand, tie-rods of unequal lengths, elongate unequally if their section is the same, under equal variations of temperature and of strain; on the other, the elements which they connect are no more parallel in this case. Thus the contrivance by which this horizontal side is consolidated, consists essentially in suspending it from a series of small parallel girders, upon which the load is brought by bolts, with nuts above, which must be screwed into the roof (II, Pl. LIX, *fig.* 1), and which themselves bring the load, by their extremities, on to the top of the two opposite faces of the fire-box. The upper limit of the load on the girders is arrived at by considering the roof divided into independent parallel strips, and each girder supporting entirely the load of one of them. Each girder is formed of a piece of forged iron, with enlargements pierced with holes for the passage of the bolts, and with enlarged feet to bring the pressure on the points of supports, or of two pieces of plate fastened together, between which the bolts pass. Single, or formed of two plates, the outline of the girder is of course that of equal resistance, and it is not applied directly against the roof in order to avoid the elevation of temperature which would result from the local exaggeration of the thickness of the metal. In almost every case however, the girder has round each bolt (II, Pl. XXIII, XXXIV, XXXIX, XLI, L, etc.), an appendage which goes down to the plate, in order to prevent the deformations which would be caused to the latter, either by excessive or insufficient tightening of some of the bolts, and also to avoid leaks by powerfully tightening up the plate against the head of the bolt and the appendage; a precaution only necessary if the bolts have been wrongly omitted to be screwed to the roof. These projections can be replaced by simple thin ferrules, but both hinder the circulation of the water, already so much interfered with, as well as the cleaning; the complete disengagement of the lower face of the girders (II, Pl. XXI) is probably preferable, but provided that the bolts are screwed.

Before going farther let us return to the conditions imposed on the two vertical sides upon which the load is thus brought.

In the high speed engine of the *Orleans* Railway, for example (II, Pl. XXXV and XXXVI) we have: grate 4,30 feet by 3,35 feet = 14,40 sq. ft.; pressure on the roof, at 9 atmospheres (effective) more than 120 tons. Under such a load the two long and thin sides which support the girders would immediately collapse, if they were not divided by horizontal rows of fixed points into vertical portions of height slight enough so as not to bend; we know by *Euler's* expression that a solid loaded on end, having its two extremities kept in the direction of the force Q, and bent by another force temporarily cannot recover by its elasticity from the action of the load if its length reaches the value $a = \pi \sqrt{\frac{EI}{Q}}$.

This division into short lengths, these fixed points, are realised by the stays themselves, through the tendency to bend, in contrary directions of the two opposite sides of the inside box and outside shell, under the direct action of the pressure of the steam. At the outset, the roof girders were always placed longways; the section of the small fire-boxes then in use being about square, it hardly mattered whether the load was brought on the one or on the other of the two pairs of parallel sides, but the longitudinal position of the girders suited better with the long tie-rods which then, as we have seen, extended from one end of the boiler to the other. But even for these short fire-boxes, it was objectionable, to load the tube-plate in this manner, as the holes then tend to become oval under the pressure, and thus introduce a special cause of leakage. This consideration, though very important, being set apart, it seems however very objectionable to bring thus the load on the two narrow sides, as in the nowadays more and more used fire-boxes, the length much exceeds the width.

It is evident that the load of the roof ought rather to be brought on the widest side seeing that the pressure per unit of surface is thereby reduced, and that besides, the position the girders longways involves very considerable scantlings in long boxes.

This very self evident modification, has long ago been adopted by builders in the United States. It was not introduced into Europe without some trouble, although it was applied by Mr. *Mc Connell* very early, in his water-space fire-boxes (Pl. II, *fig.* 5). It is at last beginning to prevail; but the principal argument in favour of the cross girders is that there is but a step to be made in order to withdraw completely the fire-box and the lower frame, from the enormous load they have to undergo. It is sufficient to lengthen the girders a little so that their extremities may rest on continuous angle irons rivetted along the inside faces of the outside box and forming

brackets (II, Pl. XXX, XXXI, XXXII, *fig.* 2, *c*, *c*, *c*; Pl. LVI, *figs.* 1 and 2; Pl. LVIII and LX, *fig.* 1; Rhenish Railways; the fine engine with eight wheels coupled, of the Midi line, exhibited by the *Creusot* Works at *Vienna* in 1873; an *express* engine for the Upper Silesian railways, etc.). The sides of the outside box thus receive the load from the brackets, instead of receiving it from the lower frame. If it is of small importance their vertical portions being freed from the corresponding strain, seeing that in their case the question is only one of extension, it is quite another thing for the inside box, the sides of which are in compression.

The girders are ordinarily placed on the brackets without being fixed thereto. When the fire is lighted, the girders may at first lift a little, on account of the greater expansion of the copper sides. Then, the pressure increasing much more rapidly than the temperature, the fire-box is compressed, subsides so to say, the girders take their places and from that moment out, the sides of the inside box escape all efforts arising from the pressure on the roof.

Connecting the girders is however very admissible, and even preferable. It is sufficient that the bolts which rest on the stays should be free to rise a little at first, on account of the excess of expansion of the copper sides, which excludes the appendages and the intermediate ferrules. This mode has been applied for several years on the Taunus Railway, where it had been remarked that the girders longways pressing on the tube plate, put the holes out of shape. The girders, eight in number, are formed of two webs rivetted on at each end to the body of a T iron, itself rivetted on to the edges of the fire-box, and act at the same time as cross-ties for staying the sides of the outside shell longitudinally above the inside box. The whole system of girders has been brought up (Pl. II, *fig.* 3) in such a way as to leave the space free for the great longitudinal tie-rods *t*, *t*..., which have been maintained. Screw-plugs, placed between the stays, allow the tartar to be easily removed and thus preserve better the plate from burning. The locomotives of the Central Illinois Railway (United States) present the same arrangements.

With existing high pressures, the girders longways are always tied more or less to the fire-box shell, and this connection is applied even to the cross stays when prolonged, although in that case, it is no longer required by the necessity of relieving the sides of the inside box; but it allows the sections of the stays to be reduced. Examples of this method are to be found on the following plates: II, XXIII; out of ten girders, the four intermediate are suspended by vertical ties to the dome and to the valve pedestal placed on the fire-box (Pl. XXIV); the cross girders are suspended

towards their middle to circular T irons rivetted on the dome; Pl. XXX to XXXII; the cross girders are suspended two and two by stirrups to T irons, and to the pedestal of the great steam dome, placed on the fire-box; Pl. XXXIV, XXXV, τ, τ; XXXIX; XLI, *fig.* 1, and XLII, *fig.* 2; XLIV, *fig.* 1, and XLV, *fig.* 2; XLVIII; LVI, *figs.* 1 and 2; LVIII and LX, *fig.* 1; in the *Steierdorf* (II, Pl. LXXV, *figs.* 1 and 2) six of the longitudinal girders are suspended, each on two points, to an angle iron forming a complete circle rivetted on to the side of the barrel which takes the man-hole and one of the valves.

Whatever may be the number of points by which each of the girders is suspended, they are ordinarily distributed symmetrically on each side of the centre. There are however exceptions, Mr. *Webb's* steel boiler (Pl. I, *fig.* 6) for example: each stay is suspended at one single point, and this point is not in the middle, whence results great inequality in the loads that the roof brings on to the faces of the inside box. p being the load on the unit of length of the stay, a the length AM and b the length MB, the loads q and q_1 which it applies at A, and at B are, admitting the points A, M, B to be always in a straight line:

$$q=\frac{3}{8}pa+\frac{1}{8}p(a-b)\frac{b}{a}, \qquad q_1=\frac{3}{8}pb+\frac{1}{8}p(b-a)\frac{a}{b}.$$

The load of the point of suspension is, by difference:

$$p(a+b)-(q+q_1)=\frac{5}{8}p(a+b)+\frac{1}{8}p\frac{a^3-a^2b-ab^2+b^3}{ab}.$$

In Mr. *Webb's* boiler we have:

$$b=0{,}57\,a, \qquad \text{whence} \qquad q=0{,}4060\,pa, \qquad q_1=0{,}1197\,pa, \qquad \frac{q}{q_1}=3{,}4.$$

The load of the tube plate is nearly three and a half times that of the back plate.

Such as ordinarily applied, the connection of the longitudinal girders with the barrel, hinders the expansion of the inside box. It is not so, if the *tie-rods* are arranged in such a manner as not to be able to work in *compression*, that is to say if they have the shape of stirrups *e*, *e*, *e* (Pl. IV, *fig.* 18) or if they present a double articulation *a*, *a* (19): arrangements which have both been tried in Germany.

Ordinary stays directly tying the two opposite sides, and longitudinal girders, are sometimes employed together: the ones in the middle part where the opposite surfaces are nearly parallel, the others laterally (II, Pl. XXI, *Krauss's* engine; *e*, *e*, *e* ties; *a*, *a* longitudinal girders); in this case no more than one girder remains on each side. In some engines of the State Railways in Saxony, they have not gone so far. Out of eight girders, applied

to similar engines of the same type, four intermediate have been suppressed, and replaced by 40 stays 4,33 inches apart.

34. *New modes of staying the roof.* — But for some years, divers builders have proposed the complete suppression of the girders, always heavy and cumbersome.

1. Some, the minority, keep to the ordinary forms and content themselves by tying the curved and the flat side together by struts fixed to the second, either directly, or by means of circular T irons, rivetted on.

2. Others replace the top of the outside box dome by a flat plate; the conditions are thus the same as for the vertical plates.

3. Others again, substitute for the flat roof of the inside box, a cylindrical dome not requiring stays, in spite of the unfavorable circumstance that the pressure acts on it from the outside, which renders its form unstable.

4. Lastly, a mixt method consists in truncating the outside roof by a horizontal plane, in connecting on the contrary by portions of a dome the flat and narrowed roof of the inside box with its longitudinal sides, and in tying by tie-rods the two flat portions, the curved portions being sufficient of themselves.

The first method has been tried on the *Oldenburg* railways, the Lower Silesia and the Mark, the Hanover, the Bavarian State railways, and with success; the dreaded leakage did not appear.

The fire-box of a parallelopiped shape, and consolidation by struts have been applied:

1. To ten engines of the Saxon State railway; the struts are, like those of the vertical sides, screwed and rivetted at the two ends in spite of their great length, 22,83 inches.

The same thing occurs in the tank-engine (Pl. II, *fig.* 4) exhibited at *Vienna*, by the *Berlin* Society of Construction.

2. To the boilers of the *Belpaire* system (Pl. I, *fig.* 4);

3. To the engines with driving-tender of the Central Belgian (II, Pl. XXX, *fig.* 3);

4. To the Great Northern American bogie engines (II, Pl. LXXV, *fig.* 4);

5. To the *Vaessen* engines (II, Pl. LXVI and LXVIII);

6. To several of the large goods engines of the Northern of Austria, etc.

The builders who apply the direct connection of the outside shell and the roof of the inside box, have not yet adopted a uniform type for the arrangement of the tie-rods; some proceed exactly in the same manner as for the vertical sides, that is to say that these tie-rods are screwed into the

plates and rivetted (Pl. II, *fig.* 4, *e*, *e*, *e*). Others desiring to avoid cold rivetting, usually adopted in France (on no conclusive grounds) replace the rivets by screws, either at one end only (*Vaessen's* engines, II, Pl. LXVI and LXVIII), or at the two ends (applied partially to *Krauss's* engines, Pl. XXI, *e*, *e*, *e*).

When the tie-rods are screwed into the two plates, as is almost always done, the substitution of screws for rivets evidently has not for object, as is often believed, to permit the deformations which arise from the unequal elongations of these long stays, to be compensated for by tightening. A screw is often also placed internally, on the side of the roof (II, Pl. XXI), which, strongly bound between the two opposite screws, makes in that way a better joint. There are no grounds for applying this second screw to the inside face as well, which is neither exposed to incrustation nor to very great variations of temperature, nor consequently to expansion and contraction, principal causes of leakage; and much less still for applying it to that face only, as is, however, sometimes done (Pl. II, *fig.* 6).

The third solution, that is to say the substitution of a cylindrical shape for the inside box (*fig.* 2), is only in some respects an attenuated application of the characteristic feature of *Bury's* old boilers. That builder endeavoured to avoid interior consolidation as much as possible, by the adoption of forms the most capable of resisting by themselves, that is to say without deflection. Thus the inside box and outside shell were cylinders surmounted by spherical segments. But the heating surface was reduced, and the junction of the horizontal cylinder with the vertical one was difficult of execution.

As far back as 1849, *Hawthorn* constructed fire-boxes with a longitudinal water space with cylindrical domes, without stays. Several station-engines of the Northern of Austria some years ago have been provided with fire-boxes having a dome and no stays. It was afterwards, however, thought prudent to connect the two domes together by rings, in order to limit the deformations (the normal absolute pressure is 9,4 atm.), without hindering the expansion of the copper side.

The mixed section (Pl. II, *fig.* 6) was introduced by M. *Becker* on the same lines. Interesting examples of this were seen at the *Vienna* Exhibition. M. *Becker* makes the tie-rods of iron.

35. *Fire-boxes with corrugated plates.* — On the Austrian State Railways, M. *Haswell* has also constructed inside fire-boxes with a dome and without stays; a deep corrugation gives the necessary stiffness to the roof. But it

is on the North Eastern of Switzerland, that this form has been subjected to conclusive trials; in consequence of which the locomotive engineer, M. *May* of *Zürich*, has adopted it for boilers working at 13 atmospheres.

Two rows of tie-rods connect the two domes; but they are established in such a manner as not to be strained in the normal state of things. They are simply laid to provide against all events, and only come into effect by the deformation of the copper roof, the extent of which they limit.

The copper plate, which forms as in the ordinary way the roof and the longitudinal sides, is corrugated; the breadth of the corrugations being from 5,9 to 6,1 inches and their depth 1,5 inches. The curves are gradually softened off from the top downwards on the sides, so as to disappear at the extremities, for the connection with the frame.

This form gives stiffness to the side because it increases its moment of inertia; it is, in principle, the contrivance which allows the roofs of buildings to be made in corrugated sheet iron, without frame work, the sheet being as to the deflection, the equivalent of a series of hollow tubes separated by intervals of the same width (Pl. I, *fig.* 22).

Thanks to this shape and in spite of the elevation of the pressure, it has been possible to make the distance between the struts of the longitudinal sides one-half greater, without one having given way, and although the vertical pressure is found in this case to be brought upon the sides. It is true that the four vertical faces, and no longer only two opposite faces, then contribute to the support of the load.

If the dome form of roof, at the same time that it suppresses the girders, reduces the strain on the vertical sides, because these then share the load, it always raises the objection : that some tubes on each side are sacrificed (Pl. II, *fig.* 2), the level of the top of the inside box remaining the same.

Another utility is attributed to the corrugations, that deposits would adhere much less in their case, than with plane surfaces; and this would be explained by the constant changes of form accompanying the variations of temperature, which would continually break up the pellicule deposited. There is nothing improbable in this; but it should be properly authenticated.

The corrugated form has also been applied by M. *Krauss*, and in a more complete manner, that is to say, along two rectangular directions, so that the roof and the longitudinal sides present a series of projections, or spherical segments corresponding to each of the squares limited by four stays (Pl. III, *figs.* 12 and 13). This *capitonnage* allows them to be placed farther apart; but its object there was above all to compensate, with less strain

on the stays and on the plates themselves, for the unequal variations of length of the two sides : iron and copper. These variations are made up partly by variations of curvature. Such is also the motive of the bends given to the plates close to their vertical edges (*figs.* 14 and 15).

Curvature along the two directions can of course be extended only to the vertical sides when they do not carry the load of the inside box, or at least only a small fraction of it.

In flat plates, the thickness of which has been reduced by wear, this *capitonnage* often arises of itself, in a certain degree.

Of all the arrangements which have just been pointed out, the best appears to be that which puts the roof of the box and the opposite surface of the outside shell, into the same conditions of staying as the vertical surfaces : that is to say, the *Belpaire* type. The stays of the horizontal surfaces have even the advantage of not being subjected like the others to efforts of flexion. Further, they are easily accessible ; and we can only complain of their exaggerating a connection which is still further already too complete, between the outside and inside boxes, and interfering too much with the expansion of the latter : a disadvantage which, at need, might be got rid of by jointing the tie-rods, as has been already done for the suspension of the girders, in order that they may not work in compression, and allow a slight rise of the roof of the inside box.

In this respect, the form adopted by M. *Becker* (Pl. II, *fig.* 6) is satisfactory ; the not stayed curved portions, *k*, *k* act in a manner, as springs, which by their deflection yield to the differences of expansion.

§ V. — **Openings made into the boiler.**

36. These openings are : 1st. Those which, indispensable for daily work, are at the same time utilised as much as possible for cleaning the boiler ; 2nd. Those which are only used for the second purpose.

The first are : the door, and sometimes two doors of the fire-box (example : *le Cantal* engine, II, Pls. LVIII to LX) ; 2nd, usually, the opening surmounted by a dome, which takes the steam pipe ; 3d, the special opening which receives the regulator, when the latter is not placed at the orifice itself of the steam pipe ; 4th, that which receives the valves or one of them, the other and sometimes both being placed on the dome ; 5th, accessorily, the points of insertion of the water-supply tubes, of the blower, of the tube which supplies *Thierry's* smoke consuming apparatus, of cocks and

gauges of the water level, of the steam-whistle, of the injection-tube for counter-steam, and of the heating tube. If openings into the boiler should be made reluctantly, above all when they are large, there should however be no hesitation in multiplying the means of access, for cleaning and mechanically scraping the inside surfaces. The expenses of maintenance are thus reduced and the durability increased. An opening large enough to allow a man to pass through is an absolute necessity, the internal erosions, which we shall come back to, rendering the interior examination of the boilers indispensable at intervals greater or less, and after the complete removal of the tubes. When there is a dome (38), the opening which it covers, fulfils also the part of *man-hole*, and where this dome contains the regulator also, the inspection of this essential organ is easy. When there is no dome, a large special opening must be made for inspecting the boiler; this may be either placed above as in *Krauss's* engine (II, Pl. XXI) where it is closed by a plate screwed on, or below, as in the Great Northern bogie-engine (II, Pl. LXXV).

Besides the large upper openings usual nowadays, the lower part of the barrel has one, and often even two holes, with *anto-clave* closing, which allow all the points of this lower region to be got at, where the principal deposits occur (II, Pls. XXIII, XXX, XXXIV, LVI, LXVI). Some engines, even with long boilers, are provided with no such lower opening (II, Pls. XLI, XLIV, L) which is a mistake.

Openings have also begun to be made in the external fire-box, up rigthly on the water spaces comprised between the longitudinal sides of the outside shell and the inside box. In the engines made for the *Berg* and the *Mark* Railway, by *Henschel*, of *Cassel*, the diameter of these openings has been carried to 5,5 inches.

The joints of the covers which are bolted on to the large openings, are often made by means of a copper wire, 0,024 inch in diameter. Sometimes the circular section is replaced by the section (Pl. I, *fig.* 17). The edges a, a, crushing under the pressure, insure greater tightness. The mud-holes, five in number at least, are thus placed: one in the smoke-box tube-plate, under the tubes; the four others, at the four angles of the fire-box, immediately above the frame. They are two inches in diameter, and are closed by plugs with conical screws. If, as sometimes occurs, these plugs are covered by the frame-plates, holes for access to them ought to be made in the latter.

We have already said (12), that the grate is raised, so that the water which surrounds the fire-box, goes down below it. Instead of useful heating sur-

face being lost in this way, objectionable surface is got rid of, unless in the very rare case of perfectly pure water. At the bottom of these water spaces, where the circulation is very imperfect, very abundant deposits are formed; and if these were subjected to a too high and long continued temperature, they would rapidly harden, and strongly adhere to the sides, which they would thus expose to the risk of being burnt. On the Northern of France, a zigzag profile is even given to the lower part of the side plates of the fire-box shells and inside boxes, forming pockets in which the deposits accumulate below the grate where the water is relatively cold, quite close to the blow-off cocks.

37. *Strengthening the periphery of the large opening.* — When the *manhole*, having only the strictly necessary dimensions, is closed by a simple cover bolted on, the latter re-establishes the continuity of form up to a certain point, and also consequently the continuity of resistance. It is however prudent in such a case, to strengthen the periphery of the opening by an inside ring.

But strengthening strongly is absolutely necessary, when a dome of large diameter, taking the steam-port, surmounts the opening, especially if the latter extends as far as the line of junction of the two cylinders. If a man can pass that is sufficient, and there can be no grounds for extending the opening (as is often done) to the sides of the dome, if it is deemed convenient to give the latter greater horizontal dimensions. The periphery of the large *gash* made in the body of the boiler, tends, in effect, to go out of shape, and the metal is there subjected to quite different strains when the opening is closed by a dome, than when shut by a cover forming a continuation of the cylindrical side.

The edges of this *gash* ought thus to be solidly stayed, so as to preserve it from all deformation; in England as well as in France this precaution has been very often omitted (II, Pls. XXX, XXXIV, XXXIX, XLI, XLIV, L, LXVI).

If this does not matter with thick plates, it is not the same thing with plates the quality of which permits the thickness to be reduced, and are therefore not so able to resist deformation as the thick ones, so that rents are the result; we shall see examples of this farther on.

Strengthening is always done by German builders (II, Pls. XXI, XXIV, XXV, etc.): an example which should be followed.

At the meeting of the 30th June 1874, the Association of Steam Users of *Manchester* charged its engineer Mr. *Fletcher*, to make experiments on the

influence of large openings, and the mode of strengthening them. The trials shall be made by hydraulic pressure, and pushed as far as fracture.

This is entering on a fruitfull path. It is quite natural to commence by the study of questions which affect safety; but that point will doubtless not be stopped at; and as has already been done with so much success by the *Mulhouse* Association, that of *Manchester* will no doubt also go into the economical questions connected with construction of boilers.

§ VI. — Dome. — Water carried over.

38. Steam domes were very much in use formerly, and after being given up, have come back into favor; it is admitted nowadays that steam carries off so much the less water the greater the height at which it is taken; also that the dome allows of running with a higher water level, an advantage highly appreciated by drivers, especially on heavy lines. Truly speaking, their utility is doubtful. The high speed with which the steam is animated can not allow any serious influence to be attributed to the increase of height at which the steam is taken, above the level of the water; the dome, it is true, increases the volume of steam, but even with the diameters adopted nowadays, the increase is almost insignificant.

However, boilers without domes are now exceptions (II, Pls. XLVI, LXIX, etc.); and the volume, particularly the diameter of this appendage has been successively increased. This diameter reaches two feet (II, Pl. XXVIII); 2,10 ft, (Pl. XXXIX); 2,20 ft, (Pls. XXX and XXXII); 2,80 ft, (Pl. XLIX and L); and even 2,95 ft, (Pl. XXXVII).

The position of the dome varies; sometimes it is placed on the fire-box (Pls. XXX and XXXII) sometimes in the middle of the barrel (XXVII and XXXIX), and sometimes towards the end thereof. (Pls. XXIV, XXVIII, XXXVII, XLI, XLIII, XLVIII, XLIX, L, LIII, LVIII, LXVI, etc.).

Some twenty years ago German engines sometimes had two domes : one on the fire-box, the other on the barrel.

The dome, that is to say, the steam port, ought to avoid on the one hand the region where the disengagement of steam, and consequently the carrying over of water are at their maximum, which is over the fire-box; on the other hand, equally the region which receives the feed-water, because a local fall of pressure is produced there.

The man-hole opening is naturally taken advantage of for placing the

dome on; it is therefore of consequence that the latter may be easily taken down. The bolted joint is often placed at the junction of the proper dome, and of a pedestal of a greater or less height upon which it is installed (II Pls. XXIII, *fig.* 3; XXVIII; XXX and XXXII, *fig.* 2; XXXIV, etc.). But it is more simple to make the joint at the cover itself, formed by the piece that carries the valves (II, Pls. XLVIII; L; LX; LXVI, etc.). The diameter of this cover must of course be not too much reduced.

The uniformity of temperature and of pressure is the less, in a locomotive boiler, less the smaller the mass of water and steam which it contains, relatively to the mass of steam which it produces and gets rid of in the unit of time, and the more the circulation of the water therein is hindered by a multitude of obstacles.

In order to get the heat better out of the gases, it is desirable that the region cooled by the feed-water, should correspond to the least hot portion of the tubes, that is to say at their front end. The middle portion of the barrel has thus come to be looked upon as the most suitable position for taking the steam.

If as we have just seen, this rule is scarcely adhered to, the reason is that, truly speaking, it is only of secondary importance, and that the conditions of the distribution of the weight, often paramount in locomotive engines, cause it to be deviated from.

The steam dome is not the only means which has been tried for reducing the amount of water carried over. Forcing the current set up when the regulator is opened, to pass over iron baffle-plates, before reaching the valve, was tried for separating the water. It was supposed that at each change of the direction of the current, the water would separate therefrom with an initial velocity directed along the last element of the obstacle. But the efficacy of this expedient amounted to nothing, or at least was so slight that it has been pretty well given up. Sometimes however, it reappears among the details of the steam openings (Pl. XXX).

The only really efficacious means, which is however applicable within but very restricted limits, for it is in opposition to the very principle of the locomotive, is to increase the steam space (26).

In stationary boilers, according to lengthened observations made by the *Société Industrielle* of *Mulhouse*, the steam carries over on the average 6,5 per cent of water. Without being as considerable as is often believed (39), the proportion is much greater in locomotives, where everything combines to increase it: the amount of heating surface; the active evaporation; the smallness of the mass of water, in every point of which steam forms and

passes off; sometimes the viscosity of the water increased by the addition of re-agents, (which are very rarely efficacious;) the smallness of the surface of the water through which all this steam passes; lastly, the insufficiency of the space in which the steam collects. If this space were greater, the velocity of the current which is produced therein by the action of the pistons would be less, and the steam could get rid, by precipitation, of a part of the moisture it contained on leaving the water.

The increase in the diameter of the barrel, now made as wide as the fire-box (4) has had the result of increasing the volume of the steam, and consequently of reducing the amount of water carried over. This influence has been well ascertained. This is not the case, however, with regard to the apparatus designed in France, under the name of *Crampton's* tube. This tube (Pl. XXI, T.T), suspended inside the boiler has a slit along its top, through which the steam passes on its way to the regulator. A precipitation of water is presumed to be effected by thus throttling the steam. Moreover, the slit is of decreasing width from the end forwards, so that the section of introduction into the tube for each length of the boiler is supposed to be in proportion to the activity of evaporation in the same length.

In this case again, the principle of abrupt changes of direction has been applied, but without being any more successful; and when this tube had been removed from a boiler, it was never put back again.

In the engines of the *Berlin Society* (Pl. II, *fig.* 2), the dome is divided into two compartments by a diaphragm, pierced with three openings, leading, the one A, into the steam pipe, the other B, into a curved tube *t*, *t*, by which steam from the fire-box is let in, while the third C is free. The dome has thus two communications with the boiler, one direct, the other by the tube *t*, *t*, the curved orifice of which opens above the opening C of the same diameter as the tube. What result could be expected from such an arrangement, which amounts to taking the steam from the most violent region, and making it pass through a tube of small section, through which it rushes with great velocity? It is supposed that the conflict of the two currents directly opposed to each other, effects the partial separation of the water. This conflict gives rise to eddies and whirls; but do these serve to get rid of the water? Is not the contrary more likely? Much better, to all appearance, would be the direct communication of the dome with the boiler, without any partition or tube, and I have no doubt that will be returned to.

If it is very difficult to dry a rapid current of steam by mechanical means,

it seems quite natural to adopt heat for the purpose. This has been tried, and by a moderate application of heat, in order to keep the steam not only saturated but even still mixed with a certain quantity of water, which is necessary for the preservation of the rubbing surfaces.

The conclusion to which the few trials made in this direction lead is, that drying by heat is scarcely easier than mechanical drying. Water mixed with steam is more difficult to evaporate than water in bulk, because the heat is only transmitted through the steam, which is a bad conductor. It is thus necessary, in order to evaporate that water, to have gases at a very high temperature. A trial was once made, for example, in some engines constructed at *Seraing*, of placing the steam dome concentrically with the chimney, continued up as far as a plate which divided the smoke-box into two compartments. The upper compartment, forming part of the boiler with which it communicated by an opening made in the tube-plate was constructed accordingly, and so was the chimney itself; but with a considerable increase of weight, there was no perceptible drying of the steam.

On the Northern of France engines with twelve coupled wheels, the object was thought to be at least partly attained. The regular heating surface (II, 262) was 1.270 square feet $\left\{\begin{array}{ll}\text{Fire-box..} & 103{,}97\\ \text{Tubes...} & 1.166{,}03\end{array}\right\}$; the tubes, 275 in number, 2,36 inches inside diameter, were only 8,20 feet long so that the temperature of the gases was very high at the moment of their leaving the tubes to pass into the dryer formed of 86 tubes of the same diameter and 3,61 feet long. The effect obtained however was next to nothing.

Far less could we dream of drying steam by the gases passing out of tubes of the ordinary length. Their heat can only be utilised in the heating of the feed water.

This was done also in the boilers of the twelve wheeled engines. The water passed through a re-heater composed of 80 tubes, 2,62 feet long, arranged in a fascia round the horizontal chimney.

The temperature of the water excluded the injector; but there was a small *Giffard* which only served to feed while standing, and of course with cold water.

MM. *Meunier* and *Hallauer* cite (*) a boiler of MM. *Sulzer*, in which the gases, after having passed along a first inside flue, passed under the boiler, and swept the upper surface of the generator on their way to the chimney. Measuring the water carried over by M. *Hirn's* calorimetric method, the

(*) *Bulletin de la Société industrielle de Mulhouse*, 1873.

authors found exactly the same number as in similar boilers, that is to say, 6,5 per cent. The modification of the circuit had thus in no way attained its end, although it lowered the temperature of the gases of 111° (P). Almost all the extra heat which was substracted from the gases went into the upper portion of the setting of the boiler. MM. *Meunier-Dolfus* and *Hallauer* do not hesitate to condemn this arrangement as essentially faulty. There is however, an advantage in cooling the gases as long as the draught does not suffer, to the gain of the mass of the boiler and the building in which it is set.

A type of boiler, with three water tubes, which is greatly adopted in *Alsace*, having 485 square feet of heating surface, re-heater not included, and evaporating 3,20 lbs of water per square foot per hour, was found by the same experimenters to give a proportion of from 3 to 4 per cent of water carried over. Two (10 horses) portable engines gave from 10 to 12 per cent.

39. The question of water carried over is moreover far from having the importance formerly attributed to it. By the verification, and it may be said the striking verification of the consequences of the mechanical theory of heat, its principles are to day among the best established. They have now led to a profound modification of the ideas admitted relatively to the influence of the water carried over by the steam. This question will come in its place, that is to say, in the study of the work of the engine, and perhaps then we shall be in a position to make known the results of the researches which the engineer of the Alsatian Association proposes to make on locomotives, by M. *Hirn's* very exact, but very delicate method; it will be sufficient, for the moment, to state the fact, that although the carrying over of water in locomotives is very considerable, it would not be very desirable to reduce the amount, and that the dome is not so necessary as is commonly believed. As long as expansion is not employed to a greater extent than it is in locomotives, the water carried over has hardly any other effect than increasing the amount of water expended, which can only be of importance in some quite peculiar cases. As the total expense of water-supply (less only that of driving the water into the boiler) hardly exceeds, even for the present powerful engines, one farthing per train mile (*), that is to say, scarcely 1,4 per cent of the total cost of haulage, a certain reduction of this figure would be of no importance.

(*) This is very nearly the average figure of the *Méditerranée* lines, for the period from 1866 to 1870, during which the total cost of haulage was, on the average, 17*d* per train mile. For 1873, in which accidental causes came in to increase the expenses, the cost of the water service rose to 0,3 d. but at the same time the total cost reached 20 d.

At the moment of starting there generally is a deposit of water in the cylinders, which is discharged by the blow-off cocks, and at the same time showers of water more or less abundant, are emitted by the chimney. Before the cylinders are heated, a condensation takes place at the contact with their sides; and it is produced afterwards normally, but less, at each admission. As to the condensation which, according to some engineers, would be produced during the period of expansion, it would take place but in altogether theorical conditions, viz. those of adiabatic expansion, within sides hermatically tight against conducting heat. We shall return to this subject farther on (350 and following).

It has long been sought to measure the proportion of water carried over, and very variable numbers have been obtained, which is quite natural, as the circumstances which influence the phenomenon vary so much, in themselves; but the method followed in the case of locomotives led to exaggerated values. It consisted in measuring the total weight of the water, and the weight of steam, expended during a certain run. The difference was the water carried over.

The expenditure of the tender, the level of the water in the boiler being brought to the initial state, gave the first weight, increased by the leakage. As to the steam, its volume was deduced from the number of revolutions of the wheels, running at a certain notch for the expansion and consequently with a determined admission : to this known volume, the specific weight of the saturated steam at the cylinder pressure, more or less below that of the boiler was applied, and given by a *Watt's* indicator. But we know at the present day that the values calculated from the specific weights of saturated steam were too low. The total amount of steam was thus estimated too low, and consequently the quantity of water too high.

Mr. *D. K. Clark* made this remark as far back as 1850, but without great notice being taken of it. The proportions of 30, and 40 per cent were thus exaggerated, at least for the conditions under which they had been obtained. It was in this way that the engineers of the Eastern of France found (*) for engines of the type 20 (*six coupled wheels*) running nearly at the maximum effort of traction, numbers varying from 24 to 39 per cent, which included not only the leakage, but also the expenditure of steam in the clearance spaces, and which had not been taken into account in the calculation of the expenditure.

(*) *De la résistance des trains*, etc., page 78.

This proportion is however always very great and also very variable, so that the evaporative power of the fuel deduced from the gross expenditure of the water would be always more or less exaggerated; comparisons of this nature ought to be made with very great caution not only between a locomotive and a stationary engine, but also between one locomotive and an other.

§ VII. — Various boilers.

40. *Boilers with two barrels.* — We have seen (II, 363) that the principle of the engine with two articulated driving-trucks, was carried out in the *Seraing* and the *Wiener-Neustadt*, then given up for a long time, and again brought forward by Mr. *Fairlie* and MM. *Meyer*. Like the *Seraing* builders, Mr. *Fairlie* adopted the boiler with two barrels, installed on an intermediate frame extending only as far as the pivots of the two trucks. Following the example of the *Vienna* builders, MM. *Meyer* have kept to the ordinary boiler, but entirely suppressed the frame.

The first form adapts itself more easily than the second to the two articulated trucks; it gives an absolutely symmetrical apparatus, so that the engine does not require to be turned; it renders the height of the level of the water above the roof of the fire-box, or at least its mean line, independent of the changes of gradient. To these real advantages, another is assumed : it is that the tubes, divided into two bundles, are not soexaggerated in length, everything else being the same, as in the simple boiler.

The length of the tubes cannot be considered independently of the other elements. It may be too great, although they are short; and suitable, although they are long. The boiler of *l'Avenir* engine, for example (II, 360) in which the direct heating surface is only $\frac{8}{158-8}=\frac{1}{18}$ of the tubular surface, the number of tubes 200, their length 15 ft, 90 and that of the grate 5 ft, 39, has tubes too long for the fire-box, or a fire-box too small for the tubes. The one ought to have been lengthened, and the other shortened, by so much; but nothing warrants the condemnation in principle of a very long simple boiler, as excluding good proportions. These are however more satisfactory in the new engine of the same type constructed for the Great Central Belgian line. The direct heating surface is 129,22 square feet, and the surface of the tubes 2.206 ft, 6 and their ratio $\frac{1}{17}$. But the tubes, 289 in number instead of 200, are only 14 ft, 76 long, while that of the grate is

8 ft, 80. It would be very interesting to compare this boiler, 27 ft, 23 in total length, with one of *Fairlie's* boilers with two barrels.

One of the favorite arguments of the partisans of very powerful engines, as against double traction, is that a large boiler utilises fuel "much better" than a boiler with small dimensions. On this account they should reject the *Fairlie* engine, which renounces the benefit of the principle admitted. As a boiler, it is equivalent to two engines coupled back to back; only, these two engines are inseparable.

For our own part, we in no way admitt the principle in question; if we have recognised (II, 363), in favour of a large boiler, the advantage "of a little more economical production of steam", it is on this sole ground, that the small boiler is proportionately more affected by external radiation; except in this point, and within very wide limits, boilers, great or small, ought equally to utilise the fuel, provided they are all well proportioned. We do not therefore see, in this respect, any serious complaint against *Fairlie's* boiler in the fact that it is in reality, not one single boiler, but two boilers. But to see any advantage therein, beyond those which we have just recognised, is really going too far. Without dwelling on the elements uselessly duplicated : smoke-boxes, chimnies, blast-pipes, steam-domes, etc., what could be more inconvenient than this double fire-box with two lateral doors, having the driver on the right and the stoker on the left, separating the two, one of whom is the head and the other the hand? And as remarked by M. *Engerth* at the time of the *Semmering* competition, what a complication, and at a the same time what an uncertainty in the stoking, with these two independent fire-boxes and this common reservoir of steam! If the pressure goes down, is the driver to tighten the two blast pipes, or one only, and which? Hence hesitation, bogglings, at times mistakes, and, probably, an increased consumption. The inferiority which the *Seraing* engine offered in this respect has been specially attributed to these causes, as is not unlikely.

As a detail of construction, we confine ourselves to mentioning (Pl. II, *fig.* 1) the form adopted by Mr. *Fairlie* in his last types. (Line from *Iquique*, *Peru*, II, 362).

Of the three hoops which constitute each of the two barrels, the first, starting from the smoke-box, is alone circular in section; the third, contiguous to the fire-box, has a constant elliptical section with the major axis vertical; the intermediate has a variable section with increasing excentricity. This disposition increases the steams-pace, while avoiding the abruptness which would result from raising the fire-box alone. It requires of

course the two hoops which are not circular, to be stayed by horizontal ties *t*, *t*, *t*.

These ties coming down upon the tubes, a place was got for them by inclining the rows of the upper tubes, which dipped down towards the smoke-box. This is advantageous for a steep gradient engine, because it increases the inclination of the line upon which the extremity of the upper tubes of the lot placed the highest, would cut the surface of the water. But why such a complicated form, and one so defective as regards resistance? What was there to hinder the barrel having a constant circular section with a diameter equal to the height of the biggest hoop (4 ft, 49), seeing that the wheels of 3 ft, 64 diameter placed under the cylindrical barrel, gave every freedom in that respect? The reason was the necessity of getting sufficient space for each of the two side foot-plates, the one for the driver, the other for the stoker without exaggerating the total width (which reaches 10,50 ft); so that this faulty form of the boiler is a consequence of the type with two barrels.

41. *Vertical boilers.* — We have cited the engines with vertical boiler on the Rigi line (II, 436). The extreme steepness of the gradients is not the only ground which may lead to the adoption of this arrangement; it may also be very proper on a level; for example, for the little locomotives used for internal transport in manufactories. A form is thus obtained very close together on plan, with very short wheel-base, and consequently great ease in running through the most difficult places, and on the sharpest curves. But if the extreme limit of curves may thus conduce to the adoption of the same arrangements, as a whole, as the extreme limit of gradients, the engine is not required in the first case to run at as low a speed, and the wheels can be driven directly. (Example: the small engine exhibited at *Vienna* by the *Harzer* Iron Works [Hartz].)

In spite of the relative smallness of its steam-space, the Rigi boiler does not appear to carry over much water. This is explained by the shortness of the tubes (6 ft, 13), which for a length of 1 ft to 1 ft, 30 are in the steam thus placed in contact with the gases at a very high temperature. But this is only a necessary consequence of the type, a consequence rather objectionable than useful for this portion of the heating surface, for this position from 3,2 to 4,3 square feet wide is in reality very badly utilised. A similar arrangement would besides, in France, be in opposition to art. 8 of he Decree of 1865.

§ VIII. — Nature of plate iron. Use of cast steel plates.

42. For a long time little attention was given to boiler plates as well as to plates for most other uses, excepting as regards fracture by extension. This condition is very important without doubt, the more so, as the low specific resistance cannot be compensated for by an increase in the thickness of the plates, even when, as in locomotives, they are not in contact with the fire. The thicker they are, the more chance there is of their being badly welded; the more they suffer in bending, and especially in having their edges turned up, operations which tend to produce not only superficial cracks, visible faults, but also to separate, internally, the badly welded layers. But hardness is the fault which must be specially guarded against.

As an example of the necessity of great ductility, a locomotive may be cited, *la Turquie*, which exploded on the 20th August 1857 on the Eastern of France. The accident could not be attributed either to the level of the water being too low (the fire-box and the tubes were perfectly intact), nor to any notable excess of pressure. The whole of the cylindrical barrell burst like glass, and numerous fragments were hurled to great distances. The very manner in which the fracture took place, seemed to show great brittleness in the metal.

The following six experiments, the two first at made *Paris*, and the four others, on account of the great force necessary, at *Guérigny* (*Nièvre*) by means of the hydraulic press employed for testing chain cables for the navy, have confirmed this surmise :

NUMBERS.	DIRECTION of the strain.	CROSS SECTIONS of the gauged portion.	BREAKING STRAIN. Total.	BREAKING STRAIN. per square inch of initial section.	LENGTH of the gauged portion.	ELONGATION at the moment of fracture.
		ins. ins. sq. ins.	tons.	tons.	inches.	per cent.
1	With the rolling....	0,39 × 0,53 = 0,21	4,500	21,25	7,87	2,8
2	do do.	0,39 × 0,55 = 0,22	»	»	do.	1,3
3	Across do.	1,99 × 0,51 = 1,01	22,90	22,16	do.	3,8
4	With do.	2,02 × 0,51 = 1,03	19,00	18,03	do.	1,9
5	Across do.	2,00 × 0,51 = 1,02	24,90	23,70	do.	5,6
6	With do.	2,00 × 0,51 = 1,02	23,10	22,19	do.	6,9
				mean 21,54		

Some years afterwards, another engine of the same series, the *Tchernaia* exploded at the moment when it was about to couple on to a train; the dome of the fire-box came off along the lines of the longitudinal rivets. In this case also, and still more certainly, there was no excess of pressure; the boiler was full of water, and in a perfect state of repair. There was nothing but the quality of the metal to account for it. The tests of the plates gave the following results:

		Square inches.	Tons.	Tons sq. in.	Inches.	Per cent.
1	Above, with the rolling.	0,261	7,123	26,89	7.00	2,67
2	do do	0,297	7,323	24,66	do	1,29
3	do do	0,282	6,448	22,86	do	0,84 (1)
4	do do	0,286	5,448	19,05	do	do (2)
5	do across	0,282	7,073	28,62	do	4,35
6	do do	0,291	7,323	25,18	do	2,24
7	do do	0,263	6,948	26,38	do	2,10
8	do do	0,282	6,698	23,75	do	0,45 (3)
9	do with the rolling.	0,262	6,823	26,04	do	2,30 (4)
10	do do	0,262	6,448	24,58	do	1,60 (5)
11	Right hand do	0,304	6,198	20,36	do	1,13 (6)
12	do across	0,292	7,575	25,92	do	4,67
13	Left hand with the rolling	0,277	6,448	23,28	do	1,27
14	do across	0,286	5,948	20,77	do	0,67
15	Back with the rolling...	0,304	7,823	25,72	do	21,3 (7)
16	do across.....	0,314	7,948	25,60	do	4,78
				mean 23,53		

(1) A flaw in the fracture.
(2) Two flaws in the fracture.
(3) One flaw in the fracture.
(4) Reheated to a cherry red.
(5) Reheated to a cherry red.
(6) A flaw in the fracture.
(7) The plate had to be reheated to straighten it.

The mean resistance of the plates of the *Turquie* (nearly 21,6 tons on the square inch, without any excessive deviations, excepting one low number, 20 tons) is certainly satisfactory. The plates were puddled ones, for which rather a lower result might have been expected. (It is to be remarked also that the two highest values correspond to the strains directed perpendicularly to the direction of the rolling, and the lowest to those along that direction : an anomaly which would seem singular, if the faults of manufacture were not borne in mind, producing local defects which affect resistance longways as well as crossways, and which are sometimes so frequent, as shown by the second table, especially in brittle plates.) But the question changes its aspect, if we examine the elongations of fracture. These are very variable, but go down to 1,9 and even 1,3 per cent.

The iron, in certain plates at least, was thus very brittle, and the resistance of the lines of rivets should have been especially affected by this

want of ductility, the more so, as the holes had been punched, as they always are, and that operation seriously alters, within a certain zone, the molecular state of a metal, which already brittle, is thereby rendered more so still. Before even any elongation was perceptible, the brittleness of the plate was shown by the mode of fracture of the samples, which gave way suddenly without any previous warning, and without appeciable contraction of the section of rupture. This fault of the metal, the only cause to which the explosion could be attributed, was also of a nature to aggravate the effects of the accident; instead of tearing along a small number of lines, the boiler projected pieces in every direction. The *Tchernaia* gave better results still as to the resistance, worse still as to the brittleness; the elongation went down to 0,67 per cent.

The numbers as to the resistance give a reply at the same time to one objection : it is sometimes supposed that the metal of a boiler which explodes must have undergone a more or less general change; now, although the terms of comparison are wanting, the high preceeding numbers prove that while the metal had kept all its tenacity in the full plate, the effort per square inch which sufficed to produce fracture along the line of least resistance of the boiler, was certainly much less. It would be well, in experiments of this sort, to test also samples containing a rivet. If iron plates, giving with gauged pieces from 7 to 8 inches, elongations of fracture inferior to one per cent are exceptions, those which give 1,5 per cent are frequent. An English puddled plate yielding under a strain of 22,6 tons (strain crossways to the rolling) gave 1,47 per cent. This was however one of those plates which are often considered as good, and which may be so for other purposes, but which ought to be rigorously rejected for steam boilers. This point cannot be too much insisted on; as it is one to which builders do not always attach it deserves importance it deserves.

If charcoal plates are generally preferable to the puddled ones, in spite of the imperfect welding to which they are more subject of the flans, the reason is less on account of their greater resistance, than on account of their greater ductility, although still often too weak. Two charcoal plates from *Audincourt* tested comparatively with those of *la Turquie* and the *Tchernaia*, gave :

The one (longways)....	25,4 tons and 10,95 per cent.
The other.....	24,1 tons and 5 per cent lengthways.
	22,5 tons and 6 per cent crossways.

An elongation of 6 per cent, for gauged pieces from 7 to 8 inches long, seems to be altogether insufficient whatever be the nature of the plate,

however great may be its resistance, even prohibiting the punching of the rivet holes. Plates from the same source, obtained by treating the coke cast irons from the South of France (*Besseges*) with charcoal possess nevertheless all the requisite qualities for boiler construction. For suspension-bridge chains, for chain-cables for the Navy, the importance of the live resistance is self-evident. If less evident for boiler-plates, this importance it is not less so in reality. The metal has not in this case to undergo shocks, but an amount of working which demands great ductility quite as imperatively. The Belgian State railways require nowadays for their *Belpaire* boilers, which work at nine atmospheres effective, plates (0,51 thick) bearing 23,3 tons lengthways, and elongating 15 per cent : conditions which exclude most puddled plates.

Some Companies, the Western Switzer for example, require charcoal plates; but it is said they prescribe nothing about resistance and elongation.

In France, locomotive boilers, as well as those of stationary engines were first placed under a common regulation, that of the Order of the 22nd May 1843, which prescribed for the thickness of cylinders of circular section and pressed from within outwards, a minimum thickness : $e = 1{,}8\ (n - 1)\ d + 3$ (*). This regulation, which was not unreasonably complained of as not taking into account the intrinsic qualities of the metal, and thus giving a sort of prize for the adoption and consequently for the production of inferior plates, was abrogated, as far as regards stationary engines, by the Decree of the 25th January 1865 (**), giving very great latitude in that respect (as well as regards responsibility, hard to be got at, at times however), without perhaps reserving the part of safety as much as should be.

Locomotive boilers remain subject to the regulation of 1843, but modified long ago (30th November 1852) by a Ministerial decision, which, taking into account, that the cylindrical barrel of locomotives is not in contact with the fire, and that they are under continued and intelligent supervision, makes them an allowance of one third on the thicknesses; at the same time stipulating that engineers should when a "boiler is presented to them for testing, assure themselves before admitting it to the benefit of the reduction, that it is made of excellent materials". This was a step made in a good way by taking the quality of the metal into account but somewhat timidly and vaguely.

(*) n, number of the *timbre* (Government stamp) in absolute atmospheres; d, internal diameter in metres; e, thickness in millimetres.

(**) The revision of this decree is now under consideration.

This process, viz. the reform of an Order by a simple ministerial decision although not legally irreproachable, is necessary often enough. Orders and Decrees cannot be always recast; and between these three courses : violating them, amending them irregularly, and enforcing what is recognised as excessive, there can be no hesitation.

43. *Measure of ductility by the elongation of fracture.* — After having insisted on the main importance of ductility, it is well to dwell a little on the real signification of the ratio, by which it is ordinarily measured.

The total elongation at the instant of fracture is generally very far from being proportional to the initial length of the gauged portion. This proportionality scarcely ever exists but with very brittle metal (and also for tempered steel). For ductile iron the total elongation of fracture comes nearer a constancy, than a proportionality to the initial length. When the limit of elasticity (the existence of this may be contested, but for the practical man, it corresponds to an abrupt increase in the permanent deformation) is exceeded, the molecular change is localised, either towards the middle or at another point determined by a want of homogeneity; thus in this region, of nearly constant length, the metal is drawn out more and more, on account of the rapid increase of the strain brought on the unit of decreasing section. The elongation is thus concentrated on a short length; and if it be distributed over the initial length of the piece, the ratio has really no precise signification if this length itself be not given. This mode of proceeding is only legitimate when the cross section remains uniform throughout the whole portion comprised between the points of reference, which ought not to be too near the extreme portions where the piece widens out. The elongation is thus uniform in itself. But this case is rare; in all the others, the method in question is a very proper one to deceive on the ductility of the metal; for bringing out those very great so called proportional elongations, it is sufficient to employ very short testing pieces.

When the pieces are of different lengths not indicated, the numbers given as measures of the ductility can generally in no way be compared; the absolute elongation would then be more explicit, less deceptive than the elongation referred to the length and the ratio of the section of *striction*, and would give a more exact measure still of the ductility.

In a very interesting note printed in 1873 on the occasion of the fine series of samples exhibited at *Vienna* by the *Creusot* Works, MM. *Schneider* thus expressed themselves (*) :

(*) *Usines du Creusot; Fers et aciers.* Pamphlet, in 4to.

"The results of tests vary according to the operation, the instrument, the preparation of the samples, far more than on account of the intrinsic quality of the metal. Thus, at the *Creusot*, in order to have comparable results, all the tested bars, were rigorously brought to the same dimensions by an identical mode of preparation, and they were confided to the same experimenter, acting with the aid of the same instrument and following the same method for all the tests."

It is thus only, in effect, that the soundness of results can be relied on.

44. *Use of skillet-cast-steel plates : First applications.* — The use of very resisting plates is naturally indicated for locomotives. Their thickness can thus be reduced, especially for the barrel, and the maximum of specific lightness attained. As to the flat surfaces, however, the advantage is less. In effect it is only possible to profit by the greater resistance of the metal in a slight degree, on two grounds : the one is that while the thickness may be reduced exactly in the inverse ratio of the elementary resistances, for those sides which are only subjected to a tensile strain, they can only be so in the inverse ratio of the square roots of those resistances, for the sides subjected to transverse flexure; the other is that with the stays applied to the two opposite surfaces (30), the solidity and resistance to leakage depend to a great extent (and even altogether if a stay-head is eaten away), on the screwing; the number of threads holding on cannot be reduced, and the thickness of the plates cannot consequently go below a limit, which is independent of the resistance of the metal.

The reduction of the number of threads might be compensated for by an increase in the thickness of stays, but unless this increase were limited to the portion inside the plates, a complication to be avoided, lightness would thus be partially sacrified to say nothing of the increased expense, and the greater obstruction in the water spaces, already inconvenient enough for the cleaning of the surfaces.

To take the inverse way, viz. to reduce the diameter of the stays, with a relative increase in their number, would be attended with the same disadvantages, and in a still greater degree.

Thin plates have moreover the advantage, if of the same nature, of suffering much less from the operations of, bending, turning over the edges, caulking the joints, etc. For fire-boxes, the main thing being that they should be made of copper, plates of verz great resistance, and consequently of reduced thickness, although in a less proportion, would seem to offer special advantages; there would thus be a more complete transmission of heat and (what is the same thing with another form) less heating and less

rapid change of the surfaces in contact with the fire. Cast steel plates seem at first to combine all the conditions: resistance, ductility, homogeneity.

The first application of these plates dates back, in France, to the year 1855. MM. *Jackson*, *Petin* and *Gaudet* had an ordinary cylindrical boiler, made of skillet-cast-steel plates at the Universal Exhibition. After the closing of the Exhibition, this boiler was placed at the disposal of the Minister of Public Works, who charged a special commission to make the necessary experiments for ascertaining the value of the new plates, and to fix the reduction of thickness which could be allowed in their case(*). The boiler 3 ft, 28 inside diameter, with hemispherical ends, was in 0,24 inch plate; the rivets also in cast steel, 0,63 inch in diameter, were 1,26 inches apart, from edge to edge.

These elements corresponded, according to the regulation formula, to an absolute pressure in work of 2,75 atmos. and to a test pressure (treble the effective pressure) $3 \times 1{,}75 + 1 = 6{,}25$ absolute atmospheres. The builders having declared that they had pushed the pressure up to 17 absolute atmospheres, the commission renewed this test, which succeeded, and under which the strain longways rose to: for the full plate, 11,3 tons on the square inch, and along the lines of rivets, 13,1 tons.

Significant as to the goodness of the joints, and as to the absence of any faults of construction in general, the sole points which the test had for object to ascertain, these numbers were far below the limit of the resistance of the metal, especially according the statement of the builders, who put forward the number of 50,8 tons on the square inch.

As the boiler required to be kept in work during a long period (nearly three years), in order to ascertain how it behaved as regards the fire, MM. *Petin* and *Gaudet* were requested to supply test pieces of a plate identical with that of the boiler. These pieces cut out in the ordinary shape and brought up exactly to gauge by a fine file, between the two widened out ends, had a cross section of 0,39 by 0,24 inch.

The altogether temporary arrangement of the testing apparatus, and the short length of the pieces between the points referred to (7 inches) were in no way adapted to the delicate measurement of the elastic elongation.

(*) Report on the application of cast steel plate to the construction of steam boilers, by MM. *Combes*, *Lorieux*, and *Couche*, secretary. *Annales des Mines*, vol. XIX, 5th series, page 311.

	DIRECTION of the strain.	LOAD. Total.	LOAD. per sq. in. of initial section.	ELONGATION under the load. Total.	ELONGATION under the load. referred to the initial length.	AREA of the section of fracture.
		tons.	tons.	inches.	per cent.	inch inch sq. in.
1	Lengthways..	3,479	36,82 fracture	1,26	17,8	0,27 × 0,16 = 0,043 or 44,44 per cent of initial section.
2	Ditto.....	2,432	25,71	0,39	5,5	inch inch sq. in.
		2,649	28,03	0,55	7,8	0,23 × 0,15 = 0,035
		2,841	29,62 fracture	1,18	15,5	or 35,46 per cent.
3	Ditto.....	2,405	25,44	0,35	5,0	
		2,734	29,84 fracture	1,26	17,8	
4	Ditto.....	2,282	24,12	0,30	4,1	inch inch sq. in.
		2,734	28,84 fracture	0,89	12,3	0,12 × 0,16 = 0,032 or 31,7 per cent.
5	Across.....	1,789	18,95	0,12	1,7	
		3,375	24,85	0,33	4,6	
		2,875	28,04 fracture	1,23	13,3	
6	Ditto..	1,634	17,30	»	»	
		1,831	18,88	0,14	2,0	
		2,349	24,85	0,29	4,0	
		2,416	25,67	0,47	6,7	
		2,664	28,21	0,67	9,4	
		Ditto 5 minutes afterwards.	28,21	0,77	10,8	
		2,714	28,71	0,87	12,5	
		2,772	29,33	1,26	17,8	

From breaking strains of from 28,8 tons to 36,7 tons, to the 50,8 tons asserted, was a long way. The experiment made in direct traction, by lifting off the loads by means of a handle worked very slowly, presented in this respect a perfect guarantee of exactness. The builders naturally put down the enormous discrepancy to the want of similarity between the plates tested and those of the boiler, the first being much softer and naturally much less able to resist.

The elongations of fracture, comprised between 0,87 and 1,33 inch, in absolute values, and between 12,3 and 17,8 per cent of the initial length of 7 inches, shew pretty great ductility.

The direction of the strain did not sensibly affect either the resistance or the ductility. A result which could be foreseen up to a certain point; the influence of the direction of the rolling, which is so great in puddled plates, disappears as we rise in the scale of qualities: this explains how some experimenters have denied it, having dealt of course with plates of superior quality. This influence persists however in certain plates of decidedly superior quality, those of Yorkshire for example; according to Mr. *R. Wilson* (*), the best plates from this district give a difference of 10 per cent between the resistances along the two directions at right angles; but one can understand it being much less marked for cast steel plates.

45. After continually working for nearly 3 years, MM. *Petin* and *Gaudet's* boiler was subjected to a minute examination. It was to be feared that the steel plate might be more sensitive than an iron one to the action of the fire, although the former escapes the liability to burn of the latter on account of the imperfect welding of the layers, and their separation under the action of the heat, as well as of its greater thickness.

True perhaps in principle, the direct advantages of the use of steel and in general of the reduction of thickness, do not appear to have been ascertained in a very authentic manner so far. M. *Harkort* of *Schönthal* (near *Wetter* on the *Ruhr*) set up in 1860 in his match manufactory, two boilers (**), one in cast steel of 0,25 Rhenish inch, the other in iron of 0,414 inch. These two boilers worked during two years exactly under the same conditions, and it was ascertained : 1st, that the plate receiving the action of the fire lasted four times aslong in the first; 2nd, that the formation of scales was much less on the steel than on the iron; 3d, that the evaporative power of the steel plate was greater by 25 per cent in the unit of time, and to the unit of fuel, 28 per cent. One single experiment, even long continued, and presenting in appearance all the guarantees of exactness, is evidently quite insufficient to cause such a superiority to be admitted in favor of steel. It can only be explained by some local circumstance, or by some inequality in conditions supposed to be identical.

The result of the examination of MM. *Petin* and *Gaudet's* boiler was satisfactory; the surfaces were throughout clean and smooth; the edges sharp; the heads of the rivets intact.

(*) *A Treatise on Steam Boilers*, by *R. Wilson*. — *Lockwood, London*, 1874.

(**) *Zeitschrift des Vereines deutscher Ingenieure*, vol. IX.

The boiler was then subjected to a new test, pushed this time to the very extreme. It was brought up in three separate operations, to 21 absolute atmospheres. Some very slight leaks showed under this pressure, which it was not possible to exceed, as the pumps lost so much. Besides the injection tube being very short, the men who were working the pump, were so near the boiler, they might have been injured if it had given way, on account of the presence of a certain quantity of air and the elasticity of the metal. The tension on the full plate exceeded 13,97 tons on the square inch, a very considerable number for a test intended only to discover accidental faults, especially at the lines of the joints.

The boiler was then cut in portions, and test pieces were taken from the different plates previously marked, in such a manner as to appreciate the position of each of them in the furnace, and that of the direction of the rolling. As in the first series of tests, the body of the piece was gauged exactly on a length of from 7 to 8 inches.

This time, not only were elongations under the load measured, starting with a load of about 25,4 tons on the square inch, but also the permanent elongations and the sections of striction corresponding to loads increasing by pretty close degrees. Above 25,4 tons, the insufficiency of the apparatus and the shortness of the pieces did not allow the elongations under the load to be measured, far less the permanent ones.

	Direct testing loads.	Successive section of striction.	Load on the sq. in. of initial section.	LENGTH of the portion gauged. Before the test.	During the test.	After the test.	Total proportional elongation under the load.	PERMANENT SET. Absolute.	Proportional.
	tons.	sq. ins.	tons.	inches.	inches.	inches.	per cent.	inches.	per cent
1st *testing piece.*	2,400	0,102	23,08	8,03	8,09	8,03	0,73	»	»
	2,700	0,102	25,99	8,03	8,11	8,09	0,98	0,059	0,73
	3,000	0,101	28,86	8,09	8,19	8,16	1,96	0,138	0,71
	3,098	0,099	29,82	8,16	8,21	8,20	2,32	0,167	2,08
	3,378	0,097	32,50	8,20	8,32	8,32	3,67	0,295	3,67
From the part against the fire.	3,564	0,094	34,28	8,32	8,42	8,42	4,90	0,390	4,90
	3,794	0,093	36,51	8,42	8,82	»	9,80	0,790	»
—		or							
Across the plate.		90,9 per cent.							
	Fracture a few seconds after the removal of the load.								
	2,544	0,098	25,75	7,95	8,01	7,99	0,74	0,039	0,49
	3,150	0,097	31,51	7,99	8,12	8,09	2,22	0,138	1,73
2nd *testing piece.*	3,272	0,093	32,75	8,09	8,19	8,16	2,97	0,216	2,72
	3,540	0,092	35,69	8,16	8,27	8,27	3,96	0,315	3,96
From the part against the fire.	3,84	0,091	38,48	8,27	8,74	»	9,9	0,787	»
—		or							
Longways of the plate.		9,24 per cent.							
	Fracture during the removal of the load.								
	2,544	0,100	25,00	7,97	8,11	8,09	1,72	0,118	1,48
	3,150	0,099	30,92	8,09	8,27	8,27	3,70	0,295	3,70
	3,272	0,093	32,14	8,27	8,32	8,32	4,44	0,354	4,44
3d *testing piece.*	3,540	0,092	34,73	8,32	8,54	8,54	7,40	0,591	7,40
	3,741	0,088	36,70	8,54	8,70	8,70	9,13	0,728	9,13
Longways of the boiler.	3,878	0,085	38,03	8,70	8,90	»	11,64	0,925	»
—		or							
Across the plate.		85,6 per cent.							
	Fracture without removal of the load.								

What is especially striking on the examination of this table, is the superiority of the resistance of the plates taken from the boiler (although the asserted figure of 50,8 tons was still very far from being reached), compared with those which had been tried three years before; and, on the contrary, the inferiority of the transversal elongations and contractions, at the moment of fracture.

The pieces of the first series must thus have been milder metal, unless it is admitted, what is very unlikely, according to the observations taken altogether, according to M. *May*, particularly (50), that the mechanical properties of the plates in the boiler had been modified by the duration of its service.

The permanent set after fracture does not figure in this table. But we see that, if the elongations under the load, notably exceed at first those which remained after its removal, the difference diminishes as the load increases, and disappear when fracture is neared. Arrived at this point, the metal behaves very nearly like a soft body, entirely retaining the deformation made on it by the load. It is clear besides, that the load under which this effect is produced would suffice for bringing about fracture, at the end of a certain time. In this case, moreover, summary observations such as can be made in workshops are being dealt with, and not at all physical experiments.

It was by operating on iron bars 50 feet long that Mr *Hodgkinson* was able to measure right through, the excess of elongation under the load over the permanent set and to ascertain that in effect the difference decreases rapidly, so that when fracture is neared, the elongation under the load and the permanent set only differ by a fraction, quite inappreciable under ordinary conditions of workshop tests, and quite to be overlooked in practice.

46. After the proceedings of the Commission on steel plates, and according to its proposition, a ministerial decision (of the 26th July 1861) authorised a reduction by one half of the regulation thickness for cylindrical boilers :

" When it is ascertained that the metal is cast steel and that it possesses at the same time a resistance to fracture by extension of 38 tons on the square inch, and a proportional elongation of $\frac{1}{15}$ (0,067) at least. "

The commission implied that the test pieces should be of the same gauged length as those on which it had operated (7 to 8 inches), but omitted to say so.

The decree of 1865, which set stationary engines free from the regulation, made no change with regard to locomotives; the allowance in question is still applicable to them, and it is combined with the reduction of $\frac{1}{3}$, which they already enjoyed, in virtue of the decision of 1852, so that for the metal which fulfils the above conditions, the thickness is reduced to : $\frac{2}{3} \times \frac{1}{2} = \frac{1}{3}$ of that which results from the formula.

In the terms of the decision of 1861 :

" The tests intended to ascertain the nature and the quality of the metal are to be made before the metal is made use of, in the presence of the superintending engineer, and by the assistance of the constructor. These tests will be made on samples taken

from the plates, which are stamped by a punch stating, their admission to the allowance of thickness."

The first application of cast steel plate to locomotives in France goes back to 1858. The Eastern of France took the initiative, and was soon followed by the *Lyons* Railway. But instead of applying this metal to the part of the boiler for which it is naturally indicated, that is to say for the cylindrical barrel, the trial was made in the first case, with the outside shell and the inside box, and in the second, with the inside box only. At that time however, the allowance of 50 per cent off the regulation thickness had not been made.

The engineers' account of the results is as follows:

1st. *Eastern of France:*

"During the Crimean war, and for some years afterwards, it was impossible to procure good Russian copper, as formerly, for the construction of locomotive fire-boxes. The bad quality of the copper employed about that period, and the progress carried out in the manufacture of steel, led the company to try whether there would not be an advantage in substituting cast steel plates for copper plates, in the construction of fire-boxes, and even steel plates for the outside shell.

"In the course of the year 1858, some goods-engines having to be constructed in the *Epernay* shops, it was resolved that the inside box and outside shell of one of them should be made of cast steel plate. This engine was completed at the end of the year 1858 and put into work on the 4th of January following. The result, as far as concerns the inside box, did not come up to the company's expectations, and after three years work, during which the engine ran a total distance of 43.254 miles, the inside box had to be taken out and replaced by one of copper.

"All the steel plates of the outside shell were 0,43 inch in thickness; those of the inside box 0,47 inch, excepting the tube plate which was 0,67 inch throughout.

"The iron plates of the barrel were 0,47 inch in thickness.

"The outside shell answered very well, but the inside box had undergone, before it was replaced, numerous and important repairs (caulking the angles, changing ferrules, stays, putting pieces round the door, on the sides, etc.).

"The tube plate was too thin. A thickness of 0,67 inch instead of 0,98 inch, the ordinary thickness of the copper plates in the strengthened portion, presented too little surface to make good joints.

"The ferrules did not hold. After three months work, the original iron tubes had to be replaced by copper tubes. In spite of that, the ferrules had often to be changed.

"The cast steel plates employed were of *too hard a nature*, and did not offer enough ductility; thus cracks showed themselves, at first in the angles of the inside box, and afterwards at the edges of the stay holes. Pieces of iron were put over these cracks, with the greatest care. But after a certain time by the effect of the contractions, the rivets got loose, leaks took place, and they could only be stopped by frequent caulking.

"With very malleable cast steel plates, such as *Krupp's*, good inside boxes could certainly be constructed, by strengthening the tube plate at the tube portion. But now

adays, as the companies can easily procure good copper, there is no advantage in employing any other metal, seeing that the difference in the cost price of the material is not much (*), that the workmanship is the same, and that the copper, after being done with, still possesses an intrinsic value of nearly $\frac{2}{3}$ of the cost price, while old steel is of almost no value. "

2nd. *Méditerranée Lines.*

" In work for three years, the fire-box shows a distance run up to the present time of 62.000 miles. It is in a good state of preservation, no crack has shown up, but I ought to say that this fire-box has always been in the hands of the same driver, and that every time it came into the engine-house, the whole of the fire was not withdrawn, so as to let it cool down slowly. This precaution, if it really be necessary, would be troublesome for a large number of engines, and is one which it would not be possible to get all the drivers to take. "

Shortly after the production of this note by M. *Delpech*, engineer of the shops, his successor M. *Boutmy*, gave somewhat less favourable particulars of the same box, and another one, which had been put into work more recently :

" Much difficulty from the beginning", said he, " was experienced in preventing leakage at the stays. But it should be remarked that these stays were of iron, screwed, 0,87 inch in diameter, and from 3,54 to 3,94 inches apart, like the copper stays. They had to be given up and replaced by copper ones. Recently examining the two boxes, some slight fissures were remarked starting from the stay-holes; did these arise from a certain hardness of the metal, or from the numerous caulkings necessitated by the leaks which took place round the iron stays? On this point no opinion can be given. In execution, the edges turned up very easily, and the rivetting of the stays held properly. The thicknesses of the tube-plates were 0,67 and 0,71 inch; those of the other sides 0,47 inch, (as in the Eastern of France boiler)."

The result of these two experiments would thus at most, negative the application of steel plate to inside boxes; and at the same time, there were faults in both cases: in the first, the metal was decidedly " too hard ", and the tube-plate too thin; in the second, the original use of iron stays had probably caused the production of cracks. We are inclined to believe that cast steel if sufficiently ductile would give good results, even for inside boxes.

A very experienced builder, M. *Mazeline*, amongst others, considered the use of cast steel as attended with advantage, especially for inside boxes.

" It works perfectly, hot, that is to say at a bright red heat," said M. *Mazeline*, " it is

(*) This position of affairs became afterwards greatly modified, to the advantage of steel.

remarkably malleable; in this respect very pure copper can alone be compared to it; it never buckles under the action of a violent fire; it is thus especially suitable for the surfaces which are in contact with the fire. It allows the thicknesses to be reduced without danger, by one half, for cylindrical sides, and one third for flat sides. "

After very numerous applications to boilers of merchant steamers, M. *Mazeline* entered into negociations with the Minister of Marine, to apply cast steel plates in boilers ordered by Government, for all the parts in contact with the fire. The mishaps which have been since undergone would have probably shaken M. *Mazeline's* confidence. This constructor had only dealt with skillet-cast-steel plates, and of superior quality; while nowadays, the generic term *cast-steel* includes a variety of very different products.

In locomotives, the cylindrical barrel is especially suited for the use of cast steel plates (44); it would be desirable to extend the application to the outside shell, when lightness is desired.

Steel plates may on the contrary be restricted to the fire-box, when a reduction, not in the total weight, but in the weight behind is necessary, in order to improve the distribution of the weight of engines with overhanging fire-boxes.

It is for this reason that the Eastern of France restricted the use of cast-steel, to the outside shell, in the case of the forty-four engines with eight coupled wheels, received in 1867 from the *Graffenstadt* works, in 1868 from the *Five-Lille* works, and in 1870 from its own *Epernay* shops. The plate was 0,51 inch in thickness; the iron-plate of the cylindrical barrel was 0,59 inch thick for a maximum working amount of 9 atmospheres.

No delay either was made in taking advantage of the allowance granted by the decision of the 26th July 1861 for the cylindrical barrel. The *Orleans* and Midi companies did so in the case of their engines with eight coupled wheels; the plates supplied by MM. *Petin* and *Gaudet*, were made from Swedish pig, cemented and cast in the skilled.

In 1868, the Eastern of France made the whole of the external envelope of its two engines with driving tender in cast steel (II, 400). The plates were in cemented steel, cast out of the skilled at *Assailly*, and rolled at *Saint-Chamond* (Loire). The thickness was : in the cylindrical barrel, 0,43 inch, for a mean diameter of 4,92 feet and a maximum pressure of 8,5 atm., and the outside shell, 0,51 inch.

The steel ingots were rolled alternately longways and crossways so that the resistance was the same in both directions. All the plates were tested and gave a mean resistance of 35 tons, with 39 for maximum, and an

elongation of fracture of 15 per cent; but the initial length of the test pieces was not given.

The *Cantal* engine, *Orleans* line, has the cylindrical barrel of skillet-cast-steel with a thickness of 0,39 inch for a mean diameter of 5,25 feet, and a maximum pressure of 9 atmospheres. (II, Pl. LVIII).

The same thing is done, in the high speed engines (II, 257) of the same lines; the diameter of the barrel is 4,07 feet, the maximum pressure 8,5 atm., and thickness of the plate 0,32 inch.

Two of these boilers gave way during working; which accidents have added to the mistrust which has for some time been inspired by steel plates. But the circumstances under which these accidents took place had nothing to do with the nature of the metal; the dome, 2 ft, 95 in diameter, was brought on to a manhole, the dimensions of which were a little less, it is true (II, Pl. XXXV), but it was no strengthened round its circumference. It was at the edge of this great hole that the rent took place; and that in one case only; in the other, it was the crown of the dome itself which came off.

Ever since, as boilers of the same series have met, under the testing pressure, with the same accident, that is to say rents at the circumference of the opening of the dome, the dome-pedestal has been replaced by a much thicker iron-plate, 0,59 inch; the opening has been reduced, its edges strengthened by a collar, and the steel crown of the dome replaced by a wrought iron one.

In 1873, the *Orleans* system had 80 engines (passenger, Pls. XXXV to XXXVII) with the boiler entirely in steel, and 32 (eight wheels coupled, Pl. XLVIII) with the outside shell only in steel, as it was required to lighten the engines behind.

The boilers of l'*Avenir* engine (363, Pl. LXXX), maximum pressure 10 atmospheres, and 4,59 feet mean diameter, is in cast steel plate of 0,37 inch. This thickness is very nearly the same (0,35) in the engines with six coupled wheels of the Midi, maximum 9 atmospheres, and 4 ft, 46 in diameter. It has been brought to 0,39 inch in the eight wheeled engines.

47. *Bessemer steel plate.* — The *Bessemer* process, every day becoming more certain of itself and of the uniformity of its different products, seemed to bring into industrial matters a series of qualities applicable to all uses, without exception; but if its success is now perfect for rails, and for axles (II, 304), for boilers it is slender. In Austria particularly, where it seemed to have been entirely taken up, more lengthened experience has brought

out drawbacks serious enough to put that application again in question. A perhaps excessive mistrust succeeded with many engineers to a premature confidence. They reject nowadays a, capricious " treacherous " metal, in the case of which it is said, the means of previous verification often fails, although perfectly reliable for wrought iron.

The French Railways at first employed *Bessemer* plate only to a slight extent, and after being previously re-cast in the skillet. After the war of 1870-71, great strictness in the supervision of the manufacture was scarcely compatible with the urgency of the renewal of stock, and *Bessemer* plate, almost excluded until then, was admitted, at least tacitly. Before that period however, some engines with a boiler made of *Bessemer* steel by *Dietrich* at *Niederbronn* had already been set to work on the little line from *Sceaux* to *Limours*.

As far back as 1868, the Northern of Austria had 78 boilers entirely in steel obtained from the converter. Although reduction of weight was the first object, nothing was gained, after all, in that respect. For a pressure of 10 atmospheres, the thicknesses are 0,39 and 0,43 inch for the barrel, and from 0,43 up to 0,59 inch for the flat sides, that is to say, very nearly the same as for iron plates.

It is quite natural that these boilers, still quite new, should act well so far. The employed plates, from *Neuberg*, are marked *extra soft*, but they only break under a load of 40 tons on the inch : too high a number not to suggest some doubts as to their ductility.

The Northern of Austria does not appear however, up to the present time, to participate in the sort of antipathy which has been manifested against *Bessemer* plate ; it was admitted for the boilers of the six wheeled coupled engines, constructed for these lines by *Sigl* in 1872; each length is formed of two plates: the one above is 0,43 inch thick, the other 0,47 the difference being on account of the influence of the deposits and erosions which act almost entirely on the lower part.

The Austrian *Staat's Bahn* has converted in its workshops, 250 tons of steel plate (from *Neuberg*) into locomotive boilers. According to M. *R. Haswell*, the tests to which all the plates were subjected only ended in the rejection of ten, and in service, five cases of cracks have been observed : four in the outside shells, one in the barrel. The author attributes them to the hardness of the metal, a hardness occasioned, according to him, by overheating the metal at the rolling.

Only ingots should be employed, he adds, obtained from the converter, without the addition of *spiegel-eisen :* such addition interfering with the

homogeneity. This amounts to saying that the cast-iron should be made from minerals pure enough to insure complete purification, without exceeding the suitable point of decarburation : and being obliged to return thereto, and much farther without the intervention of that indispensable purifier, manganese.

There seems to be nothing fundamentally wrong in the five cracks observed on the Austrian State line; however rare, accidents with plates which have stood the reception tests are undisputably unsatisfactory; and would explain how, according to the view of many engineers, *Bessemer* plate does not present as many guarantees as iron plates, even with equal thickness. We shall return farther on to the preventive remedy proposed by M. *R. Haswell.*

The South Austrian Railway, after having applied *Bessemer* steel to ten engines with eight coupled wheels, and to five others in 1870, seems little disposed to extend the experiment. It has only one single case of damage however, to record: in a side plate of an outside shell, a split arising from the rivets fixing the supports which rest on the frame plates, and very probably, because the essential conditions of the free expansion of the boiler (9), had not been provided for. They did not dare, besides, to make any considerable reduction in the thicknesses, so that even leaving the accident out of the question, steel did not appear to offer any positive advantages.

In England, the principal railway engineers were at first pretty indifferent to the question, but afterwards took it up resolutely; among them Mr. *Webb*, the successor on the London and North-Western, of the eminent *John Ramsbottom.* The result of their investigation is the exclusive use of *Bessemer* steel for the whole of the boilers, locomotive and stationary (*). It is true that Mr. *Webb* no longer seeks greater lightness, or a better distribution of the suspended weight, as, in that case again, the thicknesses are the same as for iron; it is " much greater " durability upon which Mr. *Webb* reckons absolutely.

Figs 6 (Pl. II) represents a steel boiler with cylindrical barrel, formed of only two lengths, joined end to end with covering plates.

The plate ought to support 34 tons on the square inch of initial section

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(*) " ...I am using nothing else but *Bessemer* steel of mild quality, for both locomotive and stationary engine boilers.

" From what I have seen of *Bessemer* steel, I am satisfied that *if made as we make it here,* no better material can be used. " (*Extract from a letter of Mr. Webb to the author.* 10th *March* 1874.)

with a final elongation of 25 per cent. Although the necessary complement of this number is wanting, the primitive length, or at least, the informations about the portion in striction (43), we see however, to what extent Mr. *Webb* is preoccupied with the main importance of ductility, which he tries also in another way. A strip three inches broad cut out of each plate is pierced with holes 0.63 inch in diameter, and reheated. The holes are then enlarged on a mandrel cold, until the diameter reaches 2 inches, an operation which the metal must undergo without any crack or tear. This test is besides more or less severe, according as the workman performs the operation violently or by degrees.

For some years, the great railway workshops in England, particularly at *Crewe*, have taken to manufacturing their own *Bessemer* metal. By extending their operations to boiler plates, they insure a superior quality.

The tendency to raising the pressure in locomotives has not perhaps reached its limit. A pressure of 9 atmospheres (130 lbs on the square inch) which was a few years ago the maximum in England, now is a minimum. The figures of 11,2 atm. (162 lbs. on the square inch) 12,6 atm. (180 lbs.) are no longer exceptions; and on the Metropolitan they are even going to 14 atm. (200 lbs.). With such pressures, by which at the same time both the power of the engine and the effect of the fuel are increased, very strong plates indeed are indispensable, even for ordinary diameters of the cylindrical barrel; and they become more indispensable still if, as some English Railways have begun to do, the large diameters so long objected to are adopted, which would require excessive thicknesses with ordinary plates.

In the United States, this question was discussed in 1871, at a meeting of the locomotive engineers of the principal lines. The conclusion was, that, under actual conditions, cast steel plates are not to be recommended, even for the cylindrical barrel. Prudence requires, it was said, steel plates to be very soft; and if, when so refined they are, more ductile than iron plates, they are hardly more resisting, so that the reduction of thickness almost disappears.

Let us add that the United States possess excellent iron plates, which are very thin, and work under very heavy loads; so that the preceding conclusion applies to circumstances which are quite special.

It was proved, also, in the course of the discussion, that the steel plates tried so far, failed by an excess of hardness. This excess, it is said, would go on increasing, by the very fact of being in use, in the case of the plates of which the inside box is often formed: the fact being that several of

these plates have split. On the Central Illinois line, four accidents of this kind have been observed; one to a tube plate, and three to side plates. On the *Chicago* North-Western, a side plate of the inside box split while the engine was in the shed; it was repaired, and then the opposite plate split also.

American engineers admit besides, that accidents of this nature are not relatively more frequent than others, such as flaws, to which iron plates are subject, and from which skillet-cost-steel is exempt; but as long as these defects are possible, they consider that iron plates are to be prefered.

48. The particulars furnished respecting locomotives are sometimes limited to stating that the boiler is of *cast-steel*; without adding, if the steel is from the skiller, from the *Bessemer* converter, from the *Martin-Siemens* furnace, etc. This omission, which may not always be the result of forgetfulness, is to be regretted; when a boiler, stated without further details to be of cast steel, becomes deteriorated through the faulty nature of the metal, there is at least a fair presumption that *Bessemer* steel is in question; although defective products if not absolutely, at any rate with reference to the work they have to do, can also come out of the skiller.

When we consider what the qualities of good boiler plate are, namely: great ductility, and perfect welding (which cast metal is possessed of much more than forged); when on the other hand, we find that *Bessemer* steel takes complete superiority in the shape of rails; that it has become, and with a great reduction of weight, the undisputed element on lines of great traffic, and indeed on most, without reference to the traffic; when further still, we see that in Belgium, in Austria, in England, it has generally supplanted iron for the manufacture of engine axles, particularly cranked axles, that is to say of pieces which require the longest and most difficult manipulations, and which work under the most unfavorable conditions, we ask ourselves why with such a superiority to iron for these applications, it should be so different as regards plates, or rather how we are to explain the fact, for this fact is ascertained.

The answer is, that for each application an appropriate metal is required, possessing the qualities specially called for in the particular case. For springs, a very hard metal is required; for rails, for axles, for pieces of machinery, a softer metal; for boiler plate, the superlative quality, the one which ought to predominate, without the others being too much sacrificed, is ductility, *softness*.

Cast plates ought to be extra soft; and without temper; they are only steel in name, a name they should not bear.

The degree of carburation is far from having the importance, and the significance that some persons were incited to attribute to it; for products of middling purity, and of complex nature, the industrial properties depend not only on the proportion of carbon, but also on the proportion of the other bodies associated therewith, so that, for the same purpose the proportion of carbon may and even ought to vary according to the nature of the cast iron adopted. It is thus only simply as an information that we reproduce the classification, according to the amount of carbon they contain, of the *Seraing Bessemer* steels :

DEGREE of hardness.	PROPORTION of carbon.	RESISTANCE to fracture.	ELONGATION of fracture per cent.	USES.	OBSERVATIONS.
		tons sq. sq. in.			
Very hard Hard.....	0,0065 and more. 0,0055 to 0,0065	44 to 66	5 to 10	First class springs; tools. Ordinary springs; cutting tools, files; saws, mining jumpers.	Take temper; do not weld.
Half soft.. Soft	0,0045 to 0,0055 0,0035 to 0,0045	36 to 44	10 to 20	Pieces of machinery, tyres, axles, rails (*a*), etc.	Do not weld readily. (*a*) see I (358).
Extra soft	0,0025 to 0,0035	48 to 56	20 to 25	Arms, cannon, fine plates, boiler plates.	Do not weld.

The amount of carbon contained in the *Neuberg* axles, which are of very good quality, varies from 0,0016 to 0,0038. They contain but traces of sulphur and only 0,00027 of phosphorus. Other works, having to deal with minerals of less purity, lower the amount of carbon to 0,0005, both because the purification must be pushed farther, and because what remains of those substances which are incompletely eliminated, influences the properties of the metal.

If the *extra soft* quality, alone suitable for boilers, can be obtained from the converter, it is far less easy, than the hard quality; if made with the same cast iron, ordinarily another essential condition is sacrificed, homogeneity; the manufacturer therefore avoids as much as possible, pushing the refining to that point. Thus are plates almost always harder than they should be for boilers; and works which, like those of *Neuberg*, for example, give very good steels for other purposes, have supplied boiler-plates which are either too hard or wanting in homogeneity. This fault, which has been verified by Mr. *R. Haswell* in the *Neuberg* plates, seems to be up, to a certain point, inherent to the manner in which the process itself is applied. Mr. *Bessemer* attributes it " chiefly " to the faulty manner in which the

final operation is conducted, that is to say, to the imperfect mixture of the *spiegel-eisen* throughout the mass (*); but this explanation is evidently insufficient. It is clear besides that the remedy cannot be found as M. *R. Haswell* believes, in the suppression of the final addition. It will probably be found by the addition of a material very rich in manganese, and it has already been found nowadays. In fact we have every reason to believe that it is proceeded in this way at *Crewe*, for example, and that the *spiegel-eisen* is replaced there by *ferro-manganese*, that is to say by cast iron no more containing 8, 10, 12, but 25 and even 50 and 60 per cent. of manganese. As the proportion of the final addition is in the inverse ratio of its amount of manganese, a very rich product introduces a very slight proportion of carbon, and gives what is scarcely obtained with simple *spiegel-eisen* : sufficient purity and softness at the same time.

M. *Prieger*, in Germany, Mr. *Henderson* in England, devoted themselves to the production of ferro-manganese, by different processes, although both founded on the reduction by coal of a mixture of iron and manganese minerals pulverised. The operation is slow, the production very small, the consumption of fuel very considerable, and on that account, the price very high. In France, the *Terre-Noire* Company has gone into the question; and is doubtless not the only one which has done so; and provided the difficulties of patents do not come in the way, the price of ferro-manganese may soon be expected to be no longer an obstacle to its industrial use.

49. *Sensibility of Bessemer metal to mechanical action.* — One thing after all is quite certain : very experienced engineers, and most favourably affected for cast plates, now reject *Bessemer* and only admit skillet-cast-steel as alone combining, at present, the necessary degree of softness and homogeneity.

It is also certain that *Bessemer* metal cannot stand mechanical operations, either cold, or hot, without more or less serious changes, which affect the resistance of iron much less; and that a re-heat with very carefully managed cooling can alone restore its primitive qualities (66) (**).

50. *Observations of M. May of the North Eastern of Switzerland.* — Among the engineers whose personal experience I had to appeal to

(*) " ....The want of uniformity you speak of, is due *chiefly* to the imperfect admixture at the close, of speigeleisen with the bulk of the charge of the contents of the converting vessel. "
(*Extract from a letter to the author.*)

(**) See also I, supplement, p. 496 notching steel rails.

in order to show the importance of the question of applying *Bessemer* plates to boilers, there is one whose opinion is of great weight. M. *May*, locomotive engineer of the North Eastern of Switzerland, has most perseveringly made a comparative investigation of the different kinds of plate : iron, *Bessemer* metal, and skillet-cast metal. He is probably the first engineer on the Continent who adopted very high pressures; and experience has led him to give a decided preference to crucible metal. According to him the mishaps which have arisen in the use of steel plates were owing to a bad choice of the metal, as well as want of care in using it.

He has ascertained that homogeneity is entirely dificient in *Bessemer* plate, which is too hard even on the average, and that the *Neuberg* plate, for example, in spite of its qualities, is in no way free from this double imperfection, as has been already pointed out (48). A series of boilers of this metal, constructed with all the necessary care and precautions, commenced to run in 1867. These were replaced as early as 1873, after a distance run of 115.940 miles (internal diameter 4 ft, 12, effective pressure, 10 atmospheres, thickness 0,43 inch).

The objections raised against *Bessemer* plate are: 1st, the want of homogeneity, 2nd, excessive hardness, and 3d, the frequency of alterations caused by excess of heat, either in the rolling, or in the ulterior manipulations. The third applies less to the metal than to the workmanship; but the two first affect the metal itself. Now M. *May* declares, after a lengthened practice, that these objections are in no way applicable to skillet cast steel, when well chosen and well worked, operations which present no difficulty.

Boilers of skillet-cast-plates have no doubt some times given way under the testing pressure, but this was on account of the metal being too hard and having been treated like iron, without taking into consideration the precautions required by its difference of nature.

The skillet readily yields soft and homogeneous metal; but up to the present time the converter has not succeeded in doing so, at least in a regular way (46).

M. *May* has thus given *Bessemer* up absolutely; he does not keep to iron, but adopts skilled-cast-metal, which he considers as presenting many more guarantees of safety and durability than the best iron plate (*Low Moor*, charcoal plates, etc.). When a boiler has been well constructed, with plates of skillet-cast-steel exempt from faults, and has stood the testing, it may, he says, be depended on.

The production is, besides remarkably certain in quality; a lot of plates delivered by *Krupp* to the North Eastern of Switzerland for a score of boilers,

presented no fault either on reception, during the manipulation, or at the testing of the boilers, under an effective pressure of 20 atmospheres. Under these conditions adds M. *May*, with iron, one plate out of eight if not one of six, would have been rejected, during the bending or the turning up. Out of a series of boilers (diameter 4 ft, 21; effective pressure 9 atmospheres; thickness 0,35 to 0,39 inch) in work since 1864, and having run an average distance of 259.284 miles, three are exactly the same as new, and three present on the inside, at the lower part of the cylindrical barrel, some points attacked by rust.

Others (diameter 3 ft, 30; effective pressure 12,5 atmospheres; thickness from 0,35 to 0,39 inch) in work since 1868, are in perfect condition after a distance run, short enough it is true : only 92.400 miles. Others (diameter 3 ft, 96; effective pressure 12 atmospheres; thickness 0,39 to 0,43 inch) in work since 1870, are also, perfectly intact after the same distance, nearly 92,500 miles, etc.

The North Eastern of Switzerland has recently ordered 50 new engines with skillet-cast-steel boilers. The conditions are the following: load at the limit of elasticity, 30 tons; breaking load 40 tons; elongation 16 per cent (of an initial length not given).

51. *Classification of Steel at the Creusot.* — As set forth in the note quoted farther back (43), MM. *Schneider* have abstracted in a few very substantial words and numbers a long series of experiments and observations, made with all the power and the variety of the means of investigation, at the disposal of the energetic management of the *Creusot*. We shall make some useful extracts from this note.

The degree of chemical purity is one of the most significant characters of the divers products supplied for industrial purposes, under the name of cast steel.

MM. *Schneider* divide them, in this respect, into three great classes :

A : including the less pure, and the most usual products;

C : exceptional steel which is scarcely obtained, except by putting into the skillet iron of a superior brand of *Dannemora;*

B : intermediate products between A and C.

Each of these three classes is subdivided, under the influence of the conditions of manufacture, into products differing by their mechanical properties.

Of these properties, the most characteristic, the most proper on that account to form the basis of an industrial classification, is *hardness*, measured

by the more or less great elongation, under a strain in extension, and correlatively by the contraction of the section of fracture.

Experiment has led to distribute the steel in each of the three classes, according to numbers of hardness; the elongation referred to an invariable initial length, increasing by 2 per cent from one number to the other, and of 3 per cent only towards the top of the scale for the classes B and C.

The applications of the very hard numbers having only restricted applications for the great industrial purposes, the *Creusot* manufactury has adopted the same starting point for the three classes, that is to say a metal of which the elongation of fracture is from 12 to 14, or on the average 13 per cent for an initial length of 3,94 inches and a cross section of 0,31 square inch.

As to the other limit, the maximum of elongation, it has been fixed at 35 per cent, on the average.

The maximum increasing with the purity, this number is only reached for class C; the limit is less for B, less still for A. There are thus 9 numbers of hardness for the latter, while there are 10 for B, 11 for C.

To each number of hardness corresponds in each class, a whole set of other mechanical properties, the most important of which are: the load of fracture in extension, the striction at the point of fracture, and the load corresponding to of the limit of elasticity, which, joined to the elongation, complete thus the usual description of each quality; they are abstracted in the following table.

	Numbers of hardness.	1	2	3	4	5	6	7	8	9	10	11
		p.100	p.100	p.100	p.100	p.100	p.100	p.100	p.100	p.100	p.100	p.100
Permanent elongation at the moment of fracture.	A	13	15	17	19	21	23	25	27	29	»	»
	B	13	15	17	19	21	23	25	27	29	32	»
	C	13	15	17	19	21	23	25	27	29	32	35
		tons	tons	tons	tons	tons	tons	tons	tons	tons	tons	tons
Breaking load per square inch of initial section.	A	48,4	46,4	43,3	42,1	39,6	36,6	31,6	31,1	28,4	»	»
	B	49,1	47,2	44,2	43,1	40,2	37,7	34,7	31,9	29,5	26,1	»
	C	99,8	48,4	46,2	44,0	41,0	38,8	35,8	33,0	27,4	27,5	24,8
Ratio of the section of fracture to the initial section.	A	0,80	0,749	0,697	0,646	0,595	0,544	0,493	0,441	0,395	»	»
	B	0,793	0,740	0,687	0,636	0,582	0,529	0,477	0,425	0,379	0,325	»
	C	0,788	0,732	0,678	0,647	0,570	0,514	0,460	0,409	0,363	0,310	0,268
		tons	tons	tons	tons	tons	tons	tons	tons	tons	tons	tons
Load corresponding to the limit of elasticity.	A	24,7	23,9	23,0	22,1	21,0	19,6	18,2	16,8	14,3	»	»
	B	26,0	25,3	24,5	23,5	22,6	21,4	20,1	18,7	17,7	14,9	»
	C	27,2	26,6	25,9	25,2	24,2	23,1	22,0	20,7	19,4	17,6	15,5

The original table gives also for the number of each class, the figures relative to the tempered metal. We omit these in spite of the interest which they present in themselves, because tempering cannot be applied to the uses which we have in view, and particularly to boiler plates.

What strikes at the first glance, is the regular decrease in each class; of the load of fracture, of the section of striction, and the load corresponding to the limit of elasticity, as the numbers rise.

Multiplying the load of fracture by the corresponding elongation, the following table is formed:

Numbers of hardness.	1	2	3	4	5	6	7	8	9	10	11
A	6,241	695,5	717,1	761,8	849,8	**840,5**	838,0	826.7	822.2	»	»
B	6,364	707,8	768,9	816,4	852,1	865,1	**866,7**	862 2	832.7	932.6	»
C	6,460	720,1	784,0	835,5	871,8	891,3	**894,3**	887.9	880.7	877.1	866.6

Thus in each of the three classes, the live resistance of fracture increases at first, when the numbers augment up to the same degree of the scale nearly (Nos 6 and 7), to decrease afterwards.

If, as they declare, MM. *Schneider* have succeeded, "thanks to the identity of the materials, and processes employed, in producing the metal with practical certainty, at the desired degree of hardness for each casting, so that the corresponding elongation keeps within the limits by 1 per cent more or less", the question ought by th very fact to be solved for boiler plates as well as for other applications, and that without going out of class A. No 6, having a resistance of 36 tons and an elongation of 23 per cent, would probably fulfil the essential conditions. Perhaps indeed this elongation would seem to exceed the necessary proportion, if it were not required to take into account the short length of the samples, which tends to exaggerate this proportion. Let us remark however the reserve with which the *Creusot* note expresses itself on this point:

"The rails", it says, "are always manufactured of quality A, the numbers of hardness of which vary from 1 to 5, according to the preference given by the Companies, the conditions of laying, of climate, of traffic, etc. The French Companies generally prefer hard rails; American Companies soft rails, and the Russian Companies medium rails. For tyres, pieces of machinery, axles, *plates*, the quality A is most often employed with the higher numbers; but for more security, it would be better, as certain manufacturers do, to adopt the quality B. The quality C is reserved for those consumers who are the most particular as to their brand, or for special uses, such as *certain plates*, *certain axles*."

While quite taking into account the natural tendencies of producers to specially recommend the products of the best quality, and consequently the dearest, there may be perceived here a certain distrust as regards the application to plates, of the metals of the class A, which is pretty much in conformity with M. *May's* opinion and, at any rate, in no way contradictory to Mr. *Webb's* opinion or, more correctly speaking his practice (47); the first rejects *Bessemer* plate such as it is manufactured at present; the second, who is a large enough consumer to take the trouble of manufacturing for himself, has been in a position to make sacrifices to quality, and thus probably to go in advance of most manufactories, where engineers are placed under ordinary circumstances. It must be borne in mind, besides, that M. *Webb* only requires from his steel plates a relatively low amount of work (47).

52. *Necessity of previously testing the plates.* — In all cases, the previous testing of each plate is absolutely indispensable, at least until fresh arrangements. As far back as 1861, the French Commission on plates insisted on this point. " The allowance was founded on the quality of the metal ", they said, " and it is essential that this quality should be ascertained, and this can only be done by experiment. " This verification has been asserted to be very troublesome very costly; and the Committee of the *Société Industrielle* of *Mulhouse* even went so far in the enquiry on steel plates, as to present it as almost impracticable. Nowadays it is accepted in shops, and is beginning to be recognised everywhere as necessary, and in an absolute manner, for iron plates as for steel. Thus, as M. *Petzholdt* (*) remarks, a locomotive boiler of ordinary dimensions being only composed of ten plates, three of which are of copper, subjected to the action of the steam, there can be nothing unreasonable in subjecting such a few plates to previous tests. Mr. *Webb* is not behind in this respect. The chief-engineer of the *Association of Steam-users* of *Manchester*, Mr. *Fletcher*, puts the question formally in his report(**) on a disastrous explosion which took place on the 2nd March 1874 at *Blackburn*. On his side, Mr *R. Wilson*, who has filled the same position, and

(*) " Da ein guter Locomotivkessel nur aus 7 Eisenblechen und aus 3 Kupferblechen combinirt ist, im ganzen also nur aus 10 unter Dampfdrück stehenden Blechen; so ist die Anforderung jede einzelne Platte zu untersuchen durchaus keine unmässige. " (*Fabrication Prüfung*, etc., p. 102.)

(**) " ....I would also wish to call attention to the importance of insuring a higher degree of ductility in the plates of boilers for the high pressures now employed, than has hitherto been the case, and would venture to ask, *whether it would not be well to have every plate stamped by the maker with the measure of its tenacity and its ductility, and to couple such a practice with a regular system of authorised test, so that the correctness of the brand might be checked.* "

who has brought together the results of his practice in a useful work already cited (44), establishes the insufficiency of the examination and proving of the boiler, and the necessity of a previous examination at the manufactory, of the materials which are to serve for its construction. If, as is probable, this suggestion from the most special authorities is followed by a result, it will not be the first time that these free English associations shall be found to go farther in the way of measures of safety, than all our regulations, so often charged with being excessive : a complaint which moreover would certainly fail in its aim, if it were applied to the decree of 1865.

The day will come, without doubt, when the test can be, as for rails and axles, restricted to a very small fraction of each delivery. But as long as cast plates coming from the converter do not present more complete guarantees of homogeneity, so long will previous testing be the only means of avoiding serious mishaps, and re-establishing shaken confidence. If really, as it is asserted, cracks have shown themselves after a short term of service, in boilers formed of plates the resistance and the ductility of which had been verified by previous tests, the matter is very serious. We may perhaps ask if it is quite certain that these plates have not escaped the reception tests, and that if afterwards, they had been worked up with all necessary care? There must never be any doubt on such two points as these.

Altogether, we are less forward than we thought; if plates from the converter may be admitted, they ought to be the object of severe tests, of the most minute care in the manipulation, and the working of the boilers should be most attentively watched. But it is especially desirable that the producers of *Bessemer* should endeavour to turn out, as Mr. *Webb* does not as an exception, but regularly, a resisting, ductile, and homogeneous metal; and the facts set forth by MM. *Schneider* permit us to believe that the problem will be soon solved.

Although the category A "which forms the great mass of the production of steels", not only includes the "generality of *Bessemer* and *Martin*" metals, but also certain "skillet steels", the latter only form a small item, and it is new processes that must be especially reckoned on to deliver for industrial purposes a cast metal, possessing all the qualities for a good boiler-plate.

Perhaps even the *Martin-Siemens* furnace, at first considered as a simple complement to the converter for the treatment of scraps, is destined to take the principal place in this production.

§ VII. — On certain changes undergone by boilers.

53. *Erosions and furrows.* — Boilers sometimes present inside, at the end of more or less continued work, two sorts of distinct changes, that is to say: 1st, erosions of unequal depth (*Wurmfrass, vermoulure*), one while very irregularly distributed over the part touched by the water, and especially at the lower part of the barrel (Pl. III, *figs.* 16 to 19), another while following a certain direction, as in the front and backplates of the fire-boxes, towards the turned up edges *s*, *s* (*figs.* 24 and 25), and often accompanied by other deep erosions, exactly at the bend of the plate (*figs.* 26 and 27); 2nd, continued furrows of nearly uniform depth, affecting the inside of the cylindrical barrel, either longways, or crossways, but always near the lines of rivets in plates joined by lapping, in the lapping plate and under the level of the water (Pl. III, *figs.* 20, 23); 3rd, similar furrows, either in the barrel, or in the tube plate of the smoke-box and corresponding to the outside angle iron C, joining the barrel with the tube-plate of the smoke box (Pl. III, *fig.* 28), and to the cross supports of the boiler (*fig.* 29).

These phenomena have been remarked for a long time on many lines, particular on the Northern of Austria, and under very diverse conditions of the nature of the plates and the length of service of the boilers; some examples of this are:

1st. *Hercule* engine (*fig.* 16); Styrian plates; at the end of three years of service the erosions showed themselves at the bottom of the cylindrical barrel;

2nd. *Hradisch* engine; *Krupp* steel; analogous changes equally at the end of three years;

3rd. *Mercure* engine; *Bessemer* steel; analogous changes at the end of two years and a half;

4th. *Pélopidas* engine; Styrian iron, at the end of 5 years, erosions much more marked than in the preceding cases;

5th. *Léonidas* engine; Styrian iron (*Neuberg*) (*figs.* 24-27); length of service: cylindrical barrel, 6 years; fire-box, 11 years. Its front plate especially was seriously enough changed to require immediate replacing.

6th. *Médée* engine; Neuberg iron the lower part of the cylindrical barrel, after a service of 15 years, was filled with large erosions, the depth of which reached three-quarters of the thickness of the plate.

In 1863 a *Stephenson* boiler, which had been 15 years in service exploded

in the *Leipsic* station. The cylindrical barrel, which was torn off, was formed of 6 plates lengthways, joined by a single row of rivets. There were found, along the lower joints, large furrows E (*fig.* 20) the depths of which had reached $\frac{2}{5}$ of the thickness, and which were the cause, or one of the causes of the explosion.

Very far, as we see, from being exempt from these changes, some cast steel plates are on the contrary still more subject thereto, than iron. The Midi railway has experienced this; the lower part of the cylindrical steel barrel presented these *small-pox* marks, which were rapidly deepening, while nothing of the sort had taken place in the iron boilers belonging to the same depots. M. *Damas* locomotive engineer at *Béziers* has made still more positive observation. Three strips of iron, of forged steel, and of cast-steel, were rivetted together end to end, and placed at the bottom of a boiler. Three similar bars were placed at the point where the evaporation as well as the formation of tartar, which might have a considerable influence, are at their maximum of activity, that is to say, on the roof of the fire-box. At the end of 18 months, the iron was intact; the forged steel only presented slight symptoms of change, while the cast steel was seriously attacked, particularly the sample placed on the fire-box. The tartar, *very adherent*, had to be removed to clear the surfaces, and thus in this case, very far from protecting them, seemed to be the agent, or one of the agents of the change. But there is another cause, the original state of the surfaces; in all the tested pieces one of the faces had been left rough, the other polished. Now the face of the strip in forged steel which indicates a slight commencement of erosion was the polished face; in the cast steel strip, one face was much more attacked than the other; equally the polished face. As to the iron, the immunity extended to both faces.

A series of engines (701-715) with eight coupled wheels, delivered by the firm of *Cail* in 1863, had the cylindrical barrel entirely made of steel plate, 0,93 inch thick. These engines had hardly been two years in service, and the irregular erosions had already invaded the lower portion of the cylindrical barrel. All the portions attacked were removed and replaced by iron-plate. Under the test the steel plate of the upper part of the first section of the barrel of one of these engines split along the top line, lengthways. This section carried the dome and the regulator-box, placed between the dome and the chimney. This accident, like those observed since, on the *Orleans* line (46), arose from the want of consolidation of the circumference of the large openings which weakened this plate (37); it was re-

placed in the whole series of similar engines by thicker plates, with reduced openings.

The same engine had run 145.700 miles when, on the 10th of October 1873, it exploded near *Toulouse*. The intermediate length of the barrel tore along longitudinally, and turned over downwards, shearing along the circular lines of the lap-joints by which it was joined to the adjacent lengths.

By the inquiry it was established that there had been neither excess of pressure nor want of water, that in a word, the engine had been properly driven. As to the resistance of the metal, tests gave 33,4 to 34 tons, with elongations of from 18 to 21 per cent.

But the cause of the explosion was soon discovered.

The broken plate presented, only in the portion touched by the water, erosions concentrated especially along the edge of the plate which it covered, and the depth of which reached 0,035 inch towards the middle of the length. In consequence of this accident it was decided to substitute wrought iron plates for cast steel, in the boilers of this category.

Disseminated erosions have also been observed into. engines of the *Orleans* lines, where the front length of the boiler, which receives on one side the injector tube, and on the other side that of the pump, is the most attacked; they are not serious however. Generally almost imperceptible up to about the sixth or seventh year, they often only reach at the end of a dozen or fifteen years, a maximum depth of from 0,079 to 0,158 inch. They occur especially near the supports of the boiler, which are fixed thereto by great numbers of rivets, and these rivets are sometimes the first points attacked. As to the furrows, so frequent elsewhere, there is scarcely a trace of them, so to say, in the *Orleans* engines, at least under the usual conditions, that is to say, in the neighborhood of the riveting, longways and crossways. The tube-plate is almost solely attacked in this manner. Round smoke-boxes (7) have not been adopted on these lines. There, larger and higher boxes are preferred (II, Pls. XXV, XLVIII, LVIII), which with equal length give more room for the accumulation of cinders; they have besides, probably, although that may not be the motive of the preference, some advantage as to the draught. Whatever may be, the tube plate, turned up on the top and at the sides, is attached to the cylindrical barrel by a circular angle iron *c* (Pl. III, *fig.* 28). It is towards the portion of the cylindrical sides at a', that the furrows form, circular also, but much deeper below the level of the water than above. The angle iron itself is often attacked by a fissure starting from the top of the projecting angle and developing itself more or less rapidly.

Locomotive boilers are not solely subject to these changes but they seem to be more subject thereto than others; or at least the phenomena become more rapidly manifest, as would sufficiently be explained by the nature and the discontinuity of their work and the consequent unequal expansions and contractions, the high pressures, and the activity with which the steam is produced.

54. *Causes of these alterations.* — There has been much discussion as to the causes of erosions and furrows.

a. Erosions. — Irregular erosions are due to chemical actions, depending on the nature of the metal, or that of the water, and probably on both; and as these latter vary, it is quite natural that the same should be the case with the intensity of the action.

However, the investigation which has been taken up by the locomotive department of one of the most extensive lines, the *Orleans*, seems to establish that the influence of the nature of the water may be nothing or at least slight as to that of the nature of the plate. Plates from certain sources become affected, in spite of the very diverse conditions of the feed; while others, those from *Audincourt* for example, seem to completely escape erosion.

The pressure and the temperature probably enhance the action; and this would explain up to a certain point why the effects observed nowadays are more frequent than they were formerly, after the same length of service.

The irregular distribution of erosions seems besides to be the consequence and the manifestation of the want of the homogeneity of the metal. It was first, I believe, remarked on the Upper Silesia railway, and afterwards on several lines, that these changes especially affect those points which present faults of manufacture (blows, cinder, burns). If cast steel escapes a portion of these faults, it is not however, generally, as homogeneous as was believed. It is therfore easily understood that it should thus be almost as subject as iron to these very irregularlyd istributed erosions, and at times even more so; but that it escapes completely therefrom, when well manufactured, and used with the necessary care. The steel boilers of the London and North-Western are in this case.

The influence of the nature of the steel, although what it consists in, can be positively stated, is clearly shown by a fact observed on the Northern of Austria: eighteen boilers were constructed of *Krupp's* steel plates, taken from two different supplies; the ones presented the changes in question, while the others remained intact. Boilers made later on in *Bessemer* metal appear to have equally resisted this action.

b. Furrows along the lines of rivets. — The continuous furrows which form along the rivet lines, straight or circular, especially with covering plates, have been attributed to purely mechanical actions, corresponding to the deformations of the cross-section, and to the greater strain on the metal along the line of the joint. But these mechanical actions are always developed; and they are thus insufficient to explain a phenomenon which fortunately is not general, and which shows itself very irregularly, sometimes with great rapidity, sometimes exceedingly slowly, and even not at all (53).

If besides, these actions came into play alone, all the extreme fibres placed under the same conditions would be attacked in the same manner. Two plates with the edges superposed which transmit a tensile strain tend to place themselves in their mutual continuation (Pl. I, *fig.* 18) by bending, the one at aa', the other at bb'. The joint approaches more or less to this limit of form according to the intensity of the inside pressure, the intermittences of which bring this flexion constantly into play, and to this is especially attributed the formation of furrows, by the gradual fracture of the extreme fibres. But if this cause acted alone, there should be four furrows, a, a', b, b', and as much above as below the level of the water. Now there is only a single one at a', when that line is immersed and sometimes another, on the outside, at b, but only in case of leakage. The position of the normal furrow, internal and under the water leads us to admit that the chemical action, the action of the water, plays a necessary part in the phenomenon, and that the mechanical effects facilitate it, if the metal is predisposed thereto by its own nature and that of the water. The incessant breaking up of the pellicule of tartar at the point of *maximum* flexion renews the surfaces, and delivers them unprotected to the corrosive action, which even pure water possesses, when brought to a high temperature. The absence of a second inside furrow at b' would besides be explained, up to a certain point, by the different conditions of the metal of the enveloping plate, at a', and of the enveloped plate at b'; when the boiler is empty, the position m never being completely dry, the metal at a' is constantly in contact with water.

The mechanical effects are also the less marked the thinner the plates; and this seems to confirm the fact, that the furrows (like the *vermoulure* by the way) are, it is said, unknown in the *United States*, where the thicknesses are relatively slight. But if the plates there are and can be very thin, they are also of very good quality, and in that consists perhaps the real cause of their immunity.

At the same time it is quite natural that the furrows should hold on in the case of the covering plate (63), for there is still a tendency to deformation, that is to say to flexion, but this tendency is of course counteracted by the direct action of the pressure of the steam (Pl. I, *fig.* 19). But the tendency completely disappears if the covering plate is doubled, so that the formation of the furrows could only thus be due to chemical action; which by the way is not then exerted more at the joints than elsewhere. There is not the slightest appearance of furrows, in the boilers of the Midland railway, where the double covering plate has been adopted. The chemical action was thus not sufficient to produce them, at least with the water and metal together.

Caulking. Care that it requires. — The action of the caulking tool, may also determine or hasten the formation of furrows, and caulking ought only to be confided to very careful workmen. The influence of a simple superficial stroke of the graver is well known. It is a sort of commencement of fracture, and the metal is much more brittle at the part where that has been made. In explosions, the fractures often follow the lines of caulking, even completely exempt from all signs of *furrow*, and seem to prefer the centre line of the rivets. The careless use of the caulking tool is so well understood to be one of the principal causes of the formation of furrows, that many builders, in England for example, have given up caulking the inside joints of boilers. This operation has besides other drawbacks, not inevitable, but frequent, on account of the defective shape of the tool itself, and the want of intelligence in the workman. Driving up the metal, necessary so as to prevent leakage, ought not to have the effect of causing the plate to gape beyond the portion driven up, and so bring an increase of tension on the rivet.

c. Furrows near the angle iron of the smoke-box. — As to the circular furrows which are gradually formed, either in the tube-plate of the smoke-box, at a', as on the *Orleans* lines (53) (Pl. III, *fig.* 28), or in the barrel A, just above the edge of the angle iron at a, their cause, their principal cause at least, is not doubtful; it is, as has been already said, the thrust of the tubes, a thrust distributed over two-thirds of the circle circumscribed by the cylindrical barrel. This part of the tube-plate is solidly fixed at its circumference; and the sligh change, or even none at all, at the periphery of the upper segment, is explained at once by the manner in which the thrust is distributed, and by the absence of water in that part of the boiler. And it may be conceived in the same way, how a furrow forms at times also in the plates of the barrel, at a, their connection with

the angle iron, acting and going out of shape like an ordinary lap-joint. As to the angle iron itself, intermediate between the plate and the cylindrical side, the fissures formed therein explain themselves. Leaks often come in to hasten matters.

The effects due, solely or more especially to mechanical actions might be regarded as the simple effect of an error of construction, insufficient thickness.

I ought, in general, to be proportionate to the strains; but to increase the thickness at lap joints, would be to increase the very cause of going out of shape. It is only in the case of the tube-plate and the angle iron that a further increase of thicknesses can be made; but as these thicknesses are already very considerable, it is rather in the quality of the metal that a guarantee should be sought against the drawbacks in question.

Although attention has been long colled up to these effects, they are still obscure in some points; engineers who are in a position to observe them should keep figured sketches, or even in peculiar cases, plaster casts giving the exact representation of the erosions and the furrows, and should note exactly the circumstances in which these have occurred, that is to say, the source and the nature of the plates, the analysis of the feed-water, the mileage run, and the pressure.

It should besides in all cases be expressly required that the longitudinal rivetting of each cylindrical ring of the barrel (a single line for usual diameters, as the length should then be made out of one single plate) should be placed in such a position that if below the water it should get completely dry when the boiler is emptied. Thus when the closing up is done on the side, which is generally avoided, the edge ought to be outside (Pl. III, *fig.* 21); as, if inside, a ledge would be formed on which the water might rest (*figs.* 22 and 23). Of course the position of the joint line towards the lower part must be prohibited. It is equally suitable, from this point of view, to adopt the telescopic method of joining the cylindrical rings of the barrel (Pl. I, *fig.* 6, and Pl. II, *fig.* 4), in preference to clamping at each end, especially with the larger portion in the middle (Pl. III, *fig.* 30,) which always leaves water in the boiler at α, α, at the time of emptying.

These conditions have been laid down, among others, for the boilers already cited (50) of the North-Eastern of Switzerland, of *Krupp* skillet steel, excepting the smoke-box, and these boilers working at 13 absolute atmospheres, appear to answer perfectly.

Let us also bear in mind that one of the surest means of reducing the effects in question is to withdraw the boiler from all external strain. It

ought to be quite free on its supports excepting at one end. The deformations to which the frame is subjected, particularly on curves, should not be allowed to affect the boiler, and the frame should not receive from the boiler the rigidity it should possess in itself. Proper driving of the engine has not less influence; by avoiding of course, not only excesses of pressure, that but also all abrupt changes of temperature, a careful driver can do much to check the progress of furrows. But the driver can do nothing as to erosions, which must be especially combatted by quality and purity of metal, which at the same time are hardly less efficacious against furrows.

55. *Periodical inspection of locomotive boilers.* — At the *Dresden* meeting, in 1865, the Technical Union of German railways fixed the rules to be followed for the complete examination of boilers; an operation which requires the tubes to be taken out. The first was required to take place at the end of 8 years at most, and the others at intervals of 6 years.

In consequence of an explosion which occurred in 1867 on the line from *Cologne* to *Minden*, the Minister of Agriculture, Industry, and Commerce, submitted the question afresh to the State Railways and the Companies. The most part were of opinion that the periods of 8 and of 6 years were too long; and it was agreed to reduce the periods to 5 and 4 years. But since 1869, the original periods have been returned to, and have been since sanctioned officially by the Police Regulations, modified 1st January 1872 (*). As to the renewal of the test, it takes place (**):

1. After a first distance run of 62.000 miles;
2. After every heavy repair of the boiler;
3. After every fresh distance run of 49.200 miles;
4. And in every case whatever may be the distance run, after each period of 3 years at the most.

The boiler should be, it is needless to say, completely freed from its clothing (85).

§ VIII. — The rivetting.

56. Rivetting is for wrought iron work what are, or better speaking, what were joints in wood-work. It does not present the interesting problems of pure carpentry; joining iron plates together depends on an opera-

(*) *Bahn-Polizei-Reglement für die Eisenbahnn Deutschlands.* Art. 9.
(**) *Vereinbarungen* of 1871. Arts. 205 and 206.

tion so simple in appearance, so commonplace, that to dwell on it seems almost superfluous; but it is subject to rules which are still incomplete from want of sufficient experiments, but ought to be known and followed, such as they are, that the risk may not be run of seriously compromising the resistance of the whole construction. A multitude of details of pure technology is involved, for which there is no place in this work; but riveting ought so much the less to be laid aside as, in spite of its importance, it is too often left to workshop empiricism: and this not only for steam generators. If an iron-bridge, for example, is in question, no amount of care in the part of the engineer in determining the strains will avail if the connection of the parts, that is to say, the rivetting, fails either in design or execution.

The loss of resistance along the lines of joints depends, as we shall see, on several elements. Let us admit it to be 40 per cent (a figure below the reality) for the simplest mode of rivetting, that is to say lapping with a single row of rivets. The thickness of the plates, which is necessarily uniform, thus exceeds by forty per cent, everywhere else than at the joints, that which would be sufficient if these lines of least resistance did not exist. It is easily understood how much beneficial it would be not to suppress them, which would of course be a difficult matter (71), but at any rate to reduce an excess of material which can be of use only in two cases: whenever the mass of the structure enters into consideration, and when by the extra thickness, metal in reserve meets special and local causes of wear.

57. *Rivets supposed not to be in extension. Rivetting with a single row. Modes of fracture.* — Let there be two iron plates subjected to an effort which tends to separate them in their plane of contact, perpendicularly to the line of the joint. They are pierced towards their edges and in a straight line, with circular holes receiving pins which we shall suppose placed at first with mathematical precision, filling the holes exactly and on that account subjected to shearing.

In the most simple joint and the one most used, the two plates are placed one on the other for a certain length; as an indefinite line presents as many intervals as pins, it will be sufficient to consider, together, one pin and two half intervals (Pl. I, *fig.* 20). If the effort tending to separate the plates is pushed as far as fracture, this can only take place in the plates or in the rivet, and in one of the several annexed ways, namely:

I. *In the plate.* (*a*): by extension, and then along the line of full *minimum* section, that is to say, along the line of the centres.

(*b*): by crushing, the pressure exerted by the body of the rivet on the semi-cylindrical surface of the hole, reaching the limit of the resistance of the plates to crushing.

(*c*): by transverse flexion, the same pressure which may be regarded as uniformly distributed over the solid $\alpha\beta\gamma\delta$, considered itself as placed on two supports, determining fracture in its middle.

(*d*) : by shearing, the same pressure separating from the plates the portion $\alpha\beta\gamma\delta$.

II. *In the pin* (*b'*) : by crushing, the same pressure reaching the limit of the resistance of the pin to the crushing strain.

(*d'*) : by shearing, the same pressure determining its fracture in the plane of contact of the two plates.

e being the thickness of the plates; d the diameter of the pins; l the interval between the holes from edge to edge; r the width of overlap of the two plates; R, R', R'' the resistances to fracture of the plate by extension, by crushing, and by shearing; ρ', ρ'' the resistances to fracture of the rivet by crushing and by shearing; the necessary efforts to determine fracture according to the six modes indicated have respectively for value :

$$\text{Plate} \left\{ \begin{array}{l} (a)\, t = \mathrm{R}el \\ (b)\, t_1 = \mathrm{R}'de \\ (c)\, t_2 = \frac{1}{3}\dfrac{\mathrm{R}e(r-d)^2}{d} \\ (d)\, t_3 = \mathrm{R}''er \end{array} \right.$$

$$\text{Rivet} \left\{ \begin{array}{l} (b')\, t_4 = \rho'de \\ (d')\, t_5 = \rho''\frac{1}{4}\pi d^2 \end{array} \right.$$

If these six values of t were the same, fracture would take place simultaneously according to the six modes. But equality is impossible, seeing that the effort t being given, there are six equations between the four lengths e, d, l, r.

If, as is often done in the case of iron, the three elementary resistances of the plate were admitted to be equal, and the same also as those of the rivet, the six equations would be reduced to 5, (*b*) and (*b'*) being the same; the three first would give for equality of the values t, $l = d = r$; the sixth : $d = \dfrac{e}{0{,}785}$ and the fourth $t_3 = 0$, that is to say, no resistance, which is evident.

The resistance t of one interval ought to be equal to that, t_3, of a pin, for if these resistances, one of which increases while the other diminishes, are unequal, the element which, resists not acting as much as it can and ought to do, ought to be reduced, while that which yields ought to be increased at the expense of the first. We have thus :

$$\mathrm{R}el = \pi d^2 \rho''.$$

Experience proves that for the same iron, the resistance to shearing is a little less than that to extension; but in the case which occupies us, the quality of the rivet iron being always superior, nearly reestablish the equilibrium. We can thus make :

$$R = \rho'', \quad \text{whence} \quad l = \frac{0,785d^2}{e}$$

for $e = 0,39$ inch, and $d = 0,63$ inch (section 0,25 square inch), $l = 0,79$ inch; which is in effect the interval adopted in this case.

If, as is often the case, we give the pin a diameter about double the thickness of the plates, $l = 1,24$ inch. In some of the Eastern of France engines (n° 0,239 for example),

$$e = 0,39 \text{ inch}; \quad d = 0,87 \text{ inch}, \quad \text{whence} \quad l = 1,46 \text{ inch}.$$

In fact, the intervals are not always rigorously equal. I found on a fragment detached from the boiler of the engine 0,239, values of l varying from 1,22 inch to 1,46 inch (on account of these irregularities, the heads, which we are not taking into account at this moment, and which have a diameter of 1,89 inch at the base, almost touch, and even jam each other at certain points).

The loss of resistance is measured, by supposing that the metal has undergone no change (67) by the loss of the substance of the plate along the line of centres.

In the length $l + d$ of an interval and a diameter, the length l acts alone. The resistance is thus reduced in the ratio

$$\frac{l}{l+d} = \frac{0,785d}{0,785d + e}, \tag{1}$$

for $e = 0,39$ inch, $d = 0,63$ in. $\dfrac{0,49455}{0,88455} = 0,56$,

for $e = 0,39$ inch, $d = 0,79$ in. $\dfrac{0,62015}{1,01015} = 0,61$.

In general, it is a question of rendering fraction (1) as great as possible, or $\dfrac{0,785}{0,785 + \dfrac{e}{d}}$. For a given value of e, it increases with d; there would be thus in this respect an advantage in using very thick rivets, with large intervals, seeing that l is proportional to d^2. But for boilers especially, it is not a question only of resisting the tangential effort; leaks must also be prevented, a function fulfilled by the rivet heads, to which we shall soon restore its real part. Now, in order that the plates, perfectly tight against

the rivets may not separate in the intervals, these latter must not be too great. This length would, in every case, be limited by the consideration of the effort of compression (58).

58. *Compression.* — In the hypothesis of the rivet acting as a pin, the compression of the metal is brought into play at the contact of the plate with the body of the rivet.

The surface of the normally compressed plate is de; the section stretched is el. The efforts of compression and extension per unit of surface are therefore in the ratio : $\frac{l}{d} = 0{,}785\,\frac{d}{e}$, or for $d = 2e$, 1,57. The plate thus works already much more in compression than in extension. If this has no inconveniency between these limits, it would be different for much greater values of d, and consequently of l.

It is ordinarily admitted that the resistance of iron to compression, is nearly the same as its resistances to extension and shearing. In reality, the first is greater than the others, especially than the third. But it depends essentially on the conditions which the metal is subjected to. A plate of indefinite length, loaded on a small portion of its surface, supports a much greater load per unit than a cube of the same base.

Very wrong applications often are made of the results given by experiments on the crushing of *cubes*. In hydraulic presses, where the internal pressure attains 700 or 800 atmospheres or 4,45 to 5,52 tons on the square inch, the practical load in compression for ordinary metal is exceeded; but where would fire arms be, with a tension in ordinary practice carried to 2.000 atmospheres; where would be especially certain test tubes, where the tension appears to reach 12.000 atmospheres (*) (leaving of one side *Rumford's* very exaggerated estimations), if the metals, laterally supported as they are then, could not bear without " crushing ", and in spite of the detrimental action of the high temperature arising from continued firing, very superior loads to those under which isolated cubes are crushed when loaded over the whole extent of their upper surface?

There is something similar in rivetting, as regards the metal of the plate, supported by the continuations of the plate, and for the metal of the rivet itself supported by the edges of the hole. Divers tests show that under such conditions the resistance of iron to crushing is nearly double that of its resistance to tearing. There is thus plenty of margin.

(*) *Piobert. Traité d'artillerie*, vol. II, page 324.

59. *Rivets of oblong section.* — Taking advantage of this margin, there would be, always on the hypothesis of simple pins, a very simple means of reducing the loss of matter, and consequently the loss of resistance : to give the rivets a cross section, not circular, but elongated in the direction of the effort.

If, for simplification, we suppose this section to be a rectangle dc, the condition of the equality of resistance, by tearing the plate, and by shearing the rivet, becomes $l = \frac{dc}{e}$; if we make $d = e$, $c = 3e$, we have $l = 3e$, and the resistance $\frac{l}{l+d}$ becomes 0,75. But the surface *compressed* is e^2, and the surface stretched $3e^2$. The effort of compression is three times the effort of traction, which is excessive. The concentration of the pressures on too much reduced surfaces, would bring about the crushing of the metal : a danger of which there is no fear with the circular rivet.

Oblong rivets have been tried in a boiler by Mr. *Webb;* but admitting that this shape may be applied to works of construction, it does not appear to be in its place in boilers, the condition of stanch joints always requiring the rivets to be closer together.

60. *Width of lap.* — Having the diameter and the distance apart of the rivets, the width r remains to be determined, by the double condition that the efforts to which the plate along the line of centres and the rivet resist, may not determine the fracture of the lap, either (*c*), by transverse flexion, or (*d*) by shearing.

1st. The equality of the efforts (*a*) and (*c*) (57) gives : $r = d + \sqrt{3dl}$.

For $d = 0{,}63$ inch, $l = 0{,}79$ inch we have : $r = 1{,}85$ inch and consequently the distance from the edge of the rivet to the edge of the plate or $\frac{r-d}{2} = 0{,}61$ inch; for $d = 0{,}74$ inch, $l = 1{,}06$, we have $r = 2{,}60$ and $\frac{r-d}{2} = 0{,}91$ inch.

2nd. The equality of the efforts (*a*) and (*d*) gives $r = l$. It is necessary, admitting the two resistances of the plate by tension and shearing to be the same, that the area $2 \times mn \times e$ or re be equal to el : that is to say that the width of lap ought to be equal to the interval between the rivets from edge to edge. A condition equally contrary to thick rivets, seeing that they require wider laps. We have, for the respective values above, $r = 0{,}79$ inch instead of 1,85 inch, and 1,46 instead of 2,60. A fracture ought thus

never to take place by the shearing of the plate, seeing that this mode of fracture requires, for an equal value of r, a greater effort than cross fracture (c); which is in accordance with observation.

Overlapping has the disadvantage of excluding the equality admitted thus far, of the repartition of strain on the plates. The forces t which act on the system are not directly opposed; each of them acting in the mean plane of the plate, they give rise to a couple $t \times e$, which tends to bend them at m,n and to place them in the continuation of each other (Pl. I, *fig.* 18). Hence a flexion, and an increase of strain in the extreme fibres at the indicated points, the greater, everything else equal, the thicker the plate. The very probable part of this cause in the formation of furrows has been pointed out (54).

61. *Rivetting with two rows.* — Instead of giving the rivets an elongated section, there is a much preferable means for reducing the space they take up along the line of centres, and consequently for increasing the resistance of the joint: this is to arrange them in two parallel rows, either one behind the other, or better on a zigzag line, always with the view of stanchness.

Every thing being symmetrical on either side of the line mn, the rivets of the two rows work equally; their contingent, and consequently their number in each line of least resistance, that is to say, in each of the lines of centres, is thus half less, and their interval twice as great as in the case of a simple row, and the resistance becomes, replacing l by $2\,l$.

$$\frac{2l}{2l+d} \quad \text{or} \quad \frac{2 \times 0{,}785d}{2 \times 0{,}785d + e},$$

For $d = 0{,}63$ inch, and $e = 0{,}39$ inch, we have 0,71 in place of 0,56,

For $d = 0{,}79$ inch, and $e = 0{,}39$ inch, we have 0,76 in place of 0,61.

The increase of cost corresponds only to the increase in the width of the lap.

The distance from each line of rivets to the neighbouring edge of the plate, must be great enough, as in the preceeding case; and it is necessary further that the two lines of centres should be far enough apart.

This space should be such that if the effort were pushed as far as fracture, that should take place, in the plate, along one of the lines of centres, (and hence along both at once if complete homogeneity were realisable) and not along the broken line $\alpha\beta\gamma\delta$ (Pl. III, *fig.* 31). This second mode of fracture would seem impossible, however close the two lines of rivets might be, the total section of the metal being greater along the broken line than

along the line of the centres. It has however often been observed, and even with pretty considerable distances between the two lines, among others in *Brunel's* experiments, and is explained by the change in the metal to the extent of a certain concentric zone, by the punching of the holes (67). The total length comprised between these zones being twice greater along the zigzag line than along the right line of the centers, the resistance may be less along it, in spite of its greater development.

Experiment seems to point out that the distance between the two lines of rivets should not be less than two thirds of the distance between two rivets on the same line. At *Cail and Co's*, for longitudinal rivetting, always with two rows for locomotive work, the rule shown by *fig.* 31, Pl. III is followed. The distance from edge to edge *mn* is thus 1,25 d, d being the diameter of the rivets.

62. *Rivetting with more than two rows.* — The resistance of the joints can be still further improved by increasing the lap and carrying to three, the number of the rows of pins or rivets.

If it be always admitted that the effort is distributed equally over all the rivets, the condition of the equality of resistance by shearing in all the rivets and by extension in one of the three lines of centres, gives : $l=\frac{3\times 0{,}785\, d^2}{e}$ and the resistance, along the three lines of the centres is $\frac{3\times 0{,}785\, d}{3\times 0{,}785 d+e}$.

For $d=0{,}63$ inch, $e=0{,}39$ inch, this ratio is : 0,79,
For $d=0{,}79$ inch, $e=0{,}39$ inch..... 0,82.

But as the rows are multiplied, the equality of distribution between all the rivets is more and more altered by the inevitable imperfections of the work. Theoretically even, the relations of the elements ought to be a little modified. Then t being the effort of extension applied to the unit of length of each of the plates, the first row of rivets receives from the upper plate a strain $\frac{1}{3}\,t$ which it transmits to the lower plate. At the second row, the tension of the upper plate becomes only $\frac{2}{3}\,t$, while that of the portion in contact with the lower plate is $\frac{1}{3}\,t$. The second row stops, so to say, on the way again $\frac{1}{3}\,t$, and at this row, the upper plate has a tension $\frac{1}{3}\,t$ and

the lower plate a tension $\frac{2}{3}t$. The portions facing each other, being unequally strained, lengthen unequally, and consequently the rivets take a slight obliquity. Rigorously, the two laps ought to diminish gradually in thickness.

But a more important modification would be the consequence of the addition of a third row. If one of the plates breaks along one of the extreme rows, the matter is settled; the joint is destroyed, just the same as if the whole had given way. If the breakage of one of the plates takes place along the middle row, the joint remains, much weakened it is true, the intact plate acting for the portions of the other as a covering plate. This consideration leads, in certain cases, to give up the equal distribution of the rivets, between the three rows; to reduce their total section in the two extreme rows, bringing the difference on the middle row, where the weakening of the plate is less damageable.

But is must not be forgotten that the more the number of rows increases, the more inexact is the fundamental hypothesis of the equal distribution of the effort amongst the rivets. Rivetting with three rows is moreover, never applied to boilers.

63. *Joint with covering plate.* — What has been said of the lap-joint, applies of each plate and of the covering plate, to the system who has the same thickness taken together. The tendency to flexion still exists (Pl. I, *fig.* 19), but reduced by the pressure of the steam. The deformation under the influence of the effort t remains, in effect, in principle, for each plate, and the corresponding half of the covering plate taken together. Hence an inflexion *mnp*, which the pressure of the steam applied inside, that is to say to the side opposite to the covering plate, tends to destroy.

The resistance of the joint is much improved if the single covering plate can be replaced by two bands of half the thickness, taking the two plates between them.

Each of the pins, working then by two cross-sections, can, with equality of molecular effort resist a double effort; their number may thus be reduced by one half; and this carries as we have seen, the reduced resistance from 0,56 to 0,71 and from 0,61 to 0,76 according to the thicknesses (61).

Moreover, the flexion disappears; and this is an advantage, the importance of which depends essentially on the thickness (54, 60).

The double covering-plate, rare in locomotives, has been applied to those of the little *St. John's Wood* line (*London*), only at the longitudinal joints.

64. *Rivets in longitudinal tension.* — Let us now leave the hypothesis of a pin fitting exactly into and perfectly corresponding well gauged holes, for returning to the real state of the case; to which however the consequences deduced from this hypothesis are applicable.

The conditions on which we have proceeded so far really occur in some metal bridges constructed in Germany, and in some boilers made in England. The rivets having been put in, their heads were made cold.

But, in ordinary practice, the rivet having one head previously made, its body is brought to a red heat and its second head made, either with the *riveting* hammer which gives a conical head or with the *cup-tool* or *snap*, which gives a rounded head. The rivet thus possesses at the moment it is finished, a temperature very superior to that of the plates it joins together, and to the elevation of which the mechanical work expended in making its head, being transformed into heat, contributes. Being unable to contract, its shank, after cooling, is in a state of tension, which develops, between the heads and the plates, as well as between the plates in contact, a very considerable friction.

With the simple pin, the effort necessary to determine the separation of the plates is equal to its resistance to shearing, or to the equal thereof, the resistance of the plate; with the rivet, the breaking strain is the sum of the resistance to shearing and of the two frictions developed, the one between the two plates, the other between the one of them, and the corresponding head of the rivet. It seems then, everything else equal, that the final resistance ought to be greater with rivetting hot; but it is easily understood however that it may be less. The friction, in fact, is gained, but is due to the state of tension of the rivet, a state which ought to modify, by diminishing it, the resistance to shearing.

Now, if pieces of plate joined by a rivet put in according to the ordinary workshop practice be submitted to traction, it is found that the resistance of the joint to fracture, or to dislocation, is still that which corresponds to the shearing of the rivet without tension. There is thus compensation between the friction gained, and the loss of resistance of the rivet to shearing on account of its tension. This compensation ought to come in more or less completely, according to the value of the coefficient of friction, that is to say, according to the state of the surfaces; this however varies little. If the friction besides does not increase definitively the resistance of the rivet, the increase which it necessarily involves for the final resistance of the plate, is of little consequence, as long as the values of d and of l remain the same. The rivet alone will yield, and not the plate. But the

joint is thus defective, the maximum resistance thereof corresponding to the equality of the resistances in the rivet and in the plate, and d and l having always to be determined accordingly. We shall see just now (65), what is the actual fact, which so far we have not taken into account, but in many cases, compensates nearly, in the case of the plate as in the case of the rivet, for the increase of resistance due to friction.

The *pin* is purely theoretical; possible there is only, the bolt with a nut, or the rivet put in either cold or hot, and practically only the latter, which is indeed almost always indispensable. First, the plates of the joint must be pressed one against the other; a condition very imperfectly fulfilled by cold rivetting; and it is moreover necessary to take; into account that only irons of choice quality at the very most, can stand being shaped cold and give sound heads. Putting in the rivets hot can alone, besides, make up for more or less frequent faults : holes too large, or badly centered, to which the hot and thus soft shank of the rivet moulds itself more or less.

For steam boilers, especially, the tightness of the joints overrides everything, and a rivet hole can only be rendered quite stanch by the heads of the rivets, and intimate contact of the plates; for, admitting that the rivet fits the hole exactly when hot, it does not when cool. Careful caulking is thus indispensable with cylindrical rivets. The intimate contact of the plates and the complete stopping up of the holes could only be insured by countersunk rivets but without heads. The countersinking of the holes would be realised by punching done (69) in such a manner as to give a regularly conical hole in each plate. In superposing the small bases of the cones, that is to say the sides of the entrance of the punch, the rivet put in at a bright red heat, and malleable enough to be driven up into the conical hole by its contraction which would then be free, would at each instant make up for the play which would tend to arise at its periphery from the cooling, and is really produced by the heads. But the ordinary process is more expeditious, and more simple; while the countersinking alone would certainly not by a long way give the same guarantees of solidity as with the heads. It is thus employed only as an extra, or indeed in certain cases, at places where heads are impossible.

A certain increase of expense and care in order to insure precision in rivetting is now not objected to. The schedule of clauses and conditions of the Belgian State lines, for example (*Belpaire* boilers), provides for the holes being punched a little smaller than the cold rivet and drilled out to the exact diameter, which is of course a little more than that of the cold rivet.

Starting always with the work done under the ordinary conditions of the temperature of the rivet and of the rapidity of the operation, this fact,

already cited (I, 121) was ascertained long ago: that even under the most considerable loads to which the joint is submitted in practice, the strain corresponding to one rivet never amounts to the friction, so that the rivet works only in extension.

In the face of the enormous tensions to which it is submitted, we may wonder whether the metal be not over strained. The conditions under which rivets are placed are peculiar, and scarcely conformable to the ordinary rules for the use of materials, seeing that their work is incessant, and independent of the strains which have to be resisted by the system which they hold together. Practice however re-assures us on this point: from time to time rivets put in too hot are found to explode when cooling. Some are found also which have gradually got slack, the limit of elasticity of the metal having been exceeded. But, altogether, for boilers, where avoiding leakage is so imperative a condition, rivetting done at a lower temperature would doubtless be attended with more disadvantages than advantages; and it should certainly be tried first on other constructions; without going, as they have done in Germany, to the length of putting rivets in cold.

The following, for example, is the result of some of the tests made by the French Commission on cast steel plates.

1st. *Plates delivered by MM. Petin and Gaudet.* Two pieces, 0,24 inch in thickness, were joined by a cast steel rivet, 0,53 inch in diameter; and one of the holes was made oval longways. An eye made at each end of the test piece, allowed it to be suspended from a fixed point, so that loads might be applied to it.

1st. *Test.* Total slipping under a load of 3,436 tons or 10,9 tons per square inch of the cross section of the rivet.

2nd. *Test.* Partial slipping under a load of 3,400 tons, or 10,7 tons per square inch of the cross section of the rivet.

Total slipping bringing up the portion of the plate into contact with the body of the rivet, under 3,512 tons or 10,9 tons per square inch of cross section. Now, under the pressure of the practical maximum load, the effort corresponding to a rivet, and referring to a cross section, never reaches by a long way, 10,7 tons. It thus only works in extension.

Admitting $\frac{1}{3}$ for the coefficient of friction, and considering that in order to determine slipping the load ought to reach the friction exerted on the two faces, we have for the longitudinal tension per square inch:

In the first case $\frac{1,535}{2 \times \frac{1}{3} \times 200} = 16,3$ tons per sq. inch

And in the second $\frac{0{,}985}{2 \times \frac{1}{3} \times 300} = 16{,}6$ tons par sq. inch.

A number so considerable, that we must conclude that the rivet was put in too hot.

Sometimes 0,20 and even 0,18 only, is admitted for the coefficient of friction. But these values, which would only bring out further the excess of tension in the rivets, appear evidently too low for the ordinary state of the surfaces.

In tests of this nature, the rivetting should always be done on the side of the plate where the hole is exact. On the side of the ovalised hole, the metal of the head might be there in part driven up, and thus add a resistance of quite another nature to the slipping, and thus falsify the results. But even with this precaution, there is always a certain additional resistance beyond the friction; by the very fact of the tension of the rivet, the two heads go slightly in to the plates.

In this way is explained the less load necessary to determine the slipping of a plate with an ovalised hole, bound in between two others. The friction is thus alone in play; the impression of the rivet heads has no longer any influence.

Operating thus, slipping took place:

In an experiment, under the load of 2,409 tons; corresponding tension of the rivet : 11,4 tons on the square inch;

In an other, at the end of some minutes, under the load of 2,861 tons; corresponding tension : 13,6 tons per square inch.

The tension of the rivet, and consequently the friction, should have been the same as in the first case. The greater resistance in the latter, to the separation of the plates, should thus be attributed to the cause pointed out just now.

It would result even from Mr. *Fairbairn's* already old experiments, quoted by Mr. *D. K. Clark* (*) that the friction would be greater with three plates than with two, as it would increase with the length of the rivet. This law does not seem sufficiently established, and is unnecessary to discuss this doubtful point; what is not however such, is the less resistance to the separation of the plates when it can be done without slipping from one of the rivet heads.

(*) *Recent practice*, etc., page 2.

In this fact a reduction of the advantages might be found which we have attributed to rivetting with a double covering plate, the separation of the plates requiring, with equality of tension in the rivets, less effort than with the single covering plate or with a lap.

But the final resistance, the resistance to fracture, is what we have to look at. Now, from the moment when the slipping has brought the moving plate in contact with the body of the rivet, every increase of the load brings into play the resistance of the latter to shearing, and it resists by two cross sections if the covering plate is double, while it resists by one only with the single covering plate or with a lap. The rule deduced from the pin hypothesis or the reduction of the number of rivets in each row to one half, thus subsists.

2nd. *Plates taken from the boiler.* To ascertain the resistance of the rivetting in MM. *Petin* and *Gaudet's* boiler, strips were cut out joined by a rivet. Two of these strips were subjected to successive loads of 6, 7, 8, 9, 10 $\frac{1}{2}$ and 11 tons; up to 10 tons, a load corresponding to 31,5 tons per square inch of the cross section of the rivet, no sign of fracture took place. Under 10,5, tons, a crack appeared in the outside conical head of the rivet. Under 11 tons (34,7 tons per square inch of the rivet) this crack widened out and a slight slipping, resulting from a slackening of the rivet, which had a little play, took place between the two plates. The limited resistance of the crane which supplied the fixed point, did not allow the experiment to be pushed to the complete fracture of the rivet; the chain by which it was suspended having already broken.

Fracture however would not take place by shearing in reality. This can only be done by means of apparatus arranged for the purpose, similar to that for the determination of the resistance to shearing. In general, the stretching and the flexion of the rivet, come in and determine fracture, or rather dislocation, under a load a little less than that which would produce shearing. The latter may notwithstanding be taken as a measure of final resistance.

65. *Influence of the manner in which the holes are made.* — Let us now examine the influence, to which we have already alluded, of a cause, the most irregular or at least those most diversely appreciated, effects of which require special investigation: the mode of making the holes.

The resistance of the joints, proportioned according to the rules pointed out farther back, was the object of Mr. *Fairbairn's* already old experiments, the results of which are still adopted by most constructors, although

their exactness is not so well established, or let us say as general as was supposed. The resistance being 100 for the full plate would be reduced, according to Mr. *Fairbairn*, to 70 for a lap joint and for two rows of rivets, and 56 with one row. According to Mr. *R. Wilson* (*), the numbers 100, 68, and 35 would be more exact, but trials recently made by Mr. *Kirkaldy* with reference to the *Blackburn* explosion (52), gave :

Rivetting with two rows.....	by hand.....	56,9
	by machine.....	55,5
Rivetting with one row.....	by hand.....	37,46
	by machine.....	38,66

The divergences are thus considerable, and Mr. *Fairbairn's* numbers appear to be much too high, at least for punched plates; and the opinion that such is the case is beginning to spread in England.

They agree with those which the theoretical joint, or that with simple *pin*, gives, but the accordance cannot be looked upon as a proof of their exactness. It has been supposed in effect, in order to establish the second, that the plate preserves its original resistance in the spaces l between the holes, whatever may be its nature, its quality, and whether the holes have been punched or drilled. Now this constancy true for *very ductile iron* plates, whatever may be the mode of making the holes, is true also for any plates when the holes have been drilled, but is not so for *more or less brittle iron* plates, nor for *steel* plates, *even* when *very ductile*, when the holes have been punched. Some examples further on will show (67) how far this influence may extend.

If even in the very frequent case where the plate has been affected by the punching, experiment gives a resistance for rivetted joints, in accordance with the resistance calculated on the hypothesis of the pin, the difference being neglected, it is that this weakening of the metal is very nearly compensated for by a cause special to rivetting : the friction (64) which is added to the reduced resistance of the plates, being added to the reduced resistance of the rivet, perceptibly maintains the constancy of the values.

But, and this point only is of consequence to be brought out here, it is impossible to make a safe, logical rivetting, without knowing if the holes may have reduced the resistance of the plates and in what a proportion. If this resistance has undergone no alteration, we may proceed as we have done, and determine the pitch of he rivets by treating the rivet as a pin. And it must

(*) *A Treatise on Steam Boilers.*

still be remarked that the friction, hardly more than compensating for the loss of resistance of the rivet to shearing on account of its tension, adding itself the thus intact resistance of the plate, d, ought to be a little increased at the expense of l; but it would be necessary in that, to be guided by special experiments. If the plate however, considered as very resisting, from the tests of the unpunched plates, has been seriously altered in the region of the holes, by a certain amount of brittleness, and has thus gone in this respect into the category of the less resisting and most brittle plates, the friction would be quite insufficient to compensate for this loss, and the resistance of the joint would be greatly reduced; it is thus l which should be increased.

It is therefore indispensably necessary to know the real resistance of each of the bodies to be connected, plate and rivet, and it is only then that the elements of the rivetting can be fixed, and its resistance exactly estimated. Let us add that the surest course by far, especially as regards boilers, is to exclude (67, 68) punching, unless experiment, both easy and necessary has shown the plates undergo that operation with impunity.

66. *Effect of annealing.* — Certain efforts, propagating themselves through solids, beyond the surfaces of fracture, determine therein a molecular displacement, a new state of equilibrium, to which a more or less considerable reduction of cohesion corresponds. The application of a suitable temperature may then render the molecules sufficiently free, to return to their primitive state. Annealing is in effect pretty often applied in order to correct the bad effects of the punching of the rivet holes. This is the case for example, with steel plates, on the *Orleans* lines. But annealing followed by slow cooling, effected by covering the plates with bad conductors, is a costly, as well as troublesome, and rather delicate operation. To render drilling expeditious and economical is only a question of tools; and it is certainly the safest means. Sometimes, in punching, the metal splits up to the edge of the piece; it is rejected, and no great harm is done. But if in place of complete cracks, there are only imperceptible ones, annealing will certainly not reestablishing the continuity.

Example. In an experiment by Mr. *Barnaby* (*), annealing followed by slow cooling raised from 20,6 to 35,1 tons, or an average increase of 55 per cent, the resistance of half inch steel plates, with the holes punched, 0,63 inch in diameter. If we quote these numbers, in which doubtless the mea-

(*) *Wilson. Treatise on boilers,* page 48.

sure of the real influence of annealing cannot be seen, and which are not accompanied by the necessary particulars, it is for the purpose of showing how much this important subject still requires to be investigated.

67. *Experiments on the action of the punch.* — The gravity and extent of the alteration of the metal by punching are by no means known. They would vary besides with the manner of punching, the nature, and probably also the thickness of the plates.

1st. According to Mr. *E. J. Reed* (*) trials of the resistance to tension, made on pieces coming from a plate iron reservoir, gave :

Full plate.....	21,6	tons on sq. in.
In the spaces between rivets.....	15,7 to 16,8	do do.

The alteration, of which these numbers give only an incomplete idea, seeing that the diameter and the pitch of the rivets are not given, would according to Mr. *Reed* always be still more marked for iron than for steel. This opinion is confirmed, so far as regards the resistance to shock, by the experiments cited farther back (49), and is shared by a great number of shipbuilders in England, where the application of *Bessemer* plate to hulls becomes more and more frequent. Thus many have given up punching, especially if the metal is a little brittle.

2nd. *Mr. Sharp's experiments.* Mr. *Sharp* of *Bolton*, subjected to extension strips of *Bessemer* steel, pierced with holes, some drilled, the others punched. There (**) : $e = 0{,}32$ inch, d (diameter of the holes) $= 0{,}63$ inch, $l = 0{,}87$ inch. The mean of the experiments made on three strips of each category gave :

Drilling.....	35,5	tons per sq. in.
Punching.....	23,5	do do

The first number represents the regular or normal resistance, which the drilling does not alter. The loss due to the punching, is thus, in this case, 12,2 tons per square inch, or 33,8 per cent.

3rd. *Mr. Maynard's experiments.* On breaking, by tension, strips taken from the same iron plate, and pierced with holes one inch in diameter the ones by the punch and the others by the drill, Mr. *W. H. Maynard* (***) found

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(*) *Shipbuilding in Iron and Steel. London. J. Murray*, 1869.
(**) *Wilson. A Treatise on Steam Boilers*, p. 48.
(***) *Reed. Shipbuilding in Iron and Steel*, page 339.

an excess of resistance in favor of drilling of 17 per cent, in one experiment, and of 21 per cent in another, or on the average 19 per cent.

Drilling, favourable to the resistance of certain plates, would be on the contrary, according to the same experimenter, somewhat injurious to the resistance of the intermedium, that is to say of the rivet.

By submitting to fracture pieces formed, some of two and others of three plates united by an 0,63 inch rivet, and having on account of their section, an excess of resistance such as to insure the fracture taking place in the latter, he obtained the following results (*) :

	EFFORT OF FRACTURE PER SQUARE INCH OF CROSS section of the rivet.		
	Holes punched.	Holes bored.	Difference per cent.
	Tons.	Tons.	
I. 2 Plates (one face only in shearing)....	26,8	25,6	—4,5
do 2nd experiment.....	25,6	26,0	+1,7
II. 3 Plates (two faces shearing).....	44,9	38,5	—1,41
	Mean.....		—5,6

The author attributes the inferiority of the resistance of the rivet, with the holes drilled, to the fact that the edges of the plate, more cutting than those made by the punch, act more powerfully to break into the body of the rivet; but conclusions can hardly be drawn from so restricted a number of observations.

However that may be, the diminution of resistance seems to be 5,6 per cent. The advantage being 19 per cent on the one side, and the loss 5,6 per cent on the other, the author deduces therefrom the singular conclusion, that there is altogether a gain of 13,4 per cent in favour of drilling! Let us suppose that without changing anything else in the riveting, punching be replaced by drilling; if the resistance of the rivets is reduced by that fact 5,6 per cent, it will be exactly the same with reference to the resistance of the joint, and in that case the excess of resistance of 19 per cent in favour of the plate, is of little consequence. The compensation pointed out, doubtless does not give the author's idea properly. The result of the above figures would be that the quantities d and l should be modified by taking into account the great increase of resistance for the plate, and the slight decrease

(*) *Reed, Shipbuilding in Iron and Steel*, page 530.

for the rivet; that in a word, the proportion of the elements of riveting should vary with the mode of piercing the holes, so long as this mode influences the specific resistance of one of the elements only, or of both, but unequally.

68. *Lower limit of the diameter of holes made by the punch in a plate of a given thickness.* — The punch, slightly conical to avoid the friction, which would otherwise be developed between it and the sides of the hole, cannot pierce, in a plate of a given thickness e, a hole of a diameter d below a certain limit. The surface to cut out is πde, and the effort to be exerted by the punch $\pi de \times R''$. R' being the resistance to crushing of the punch, it is necessary that $\pi de \times R'' =$ at the most, $\frac{1}{4}\pi d^2 . R'$; whence $e =$ at the most: $\frac{1}{4}\frac{R'}{R''}d$. It is ordinarily admitted that the resistance to crushing of the tool, in tempered steel, is 4 times the resistance of iron to shearing; for $R' = 4R''$, $d =$ at least e.

For ordinary riveting, this condition, as we have seen, is always amply fulfilled, and never forms an objection against punching: but this expeditious and economical method has been formally prohibited as a measure of prudence, on some railways; among others, on the Austrian State railway, and the North-Eastern of Switzerland. On the latter, besides, the holes drilled in the steel plates (which are exclusively employed) (50), have a large countersink towards the outside, intended to keep the plates well in contact, in the case where a head might give way. The rivets however are not of steel, but of iron of choice quality and fine grain, which seems to support the operation better.

69. *Conical shape of the holes pierced by the punch.* — Drilling ordinarily gives cylindrical holes. In punching, two shearings are effected at the same time in the plate; the one, from above downwards, starts from the convex edge of the punch, the other from below upwards, starts from the concave edge of the block. These two circumferences have not quite the same diameter, the second having to be a little larger in order to get rid of the friction, and to facilitate the plug getting out.

Now neither of these edges cuts exactly according to the cylinder to which it belongs; each body tends to carry away metal from the plate beyond the operating edge, that is to say more for the punch, and less for the block; hence two layers of truncated cone. For iron, the inclination to the axis seems to be very nearly constant and

equal to $\frac{1}{8}$; on that account, the surface cut should be continuous, that is to say that the two layers would belong to the same conical surface, if there were between the diameter d of the punch, the diameter d' of the hole in the block, the thickness e of the plate and the inclination $\frac{1}{i}$, the relation :

$$d' = d + \frac{2e}{i}. \qquad \text{For} \quad \frac{1}{i} = \frac{1}{8},\ d' = d + \frac{1}{4}e.$$

If d' is greater than this value, the lower layer envelops the other. If d' is smaller, the reverse takes place.

It is the second case which takes place in practice; and thus is explained the aspect (Pl. I, *fig.* 21) ordinarily presented by the plugs when removed by the punch; the continuation of the lower conical surface, cut by the edge of the mould, is let in under that which is cut by the edge of the punch, and which forms towards the middle of the thickness a very decided fringe mnp. Secondary fringes, much less clearly defined, f, f, f, are due to the tearing of the metal, and are the more numerous in proportion to the brittleness of the metal.

As d' is always greater than d from the reason pointed out, the hole has always a mean conicity : $\frac{1}{2}\frac{d'-d}{e}$; or d' being often $1{,}1\,d$, $0{,}05\,\frac{d}{e}$; or for $d = 0{,}79$ inches, $e = 0{,}39$ inch, $0{,}1$. The countersinking draw due to this conicity, and especially the economy, are the motives for the preference given to punching, particularly by many iron shipbuilders, in spite of the local alteration which results therefrom in the plate. It is necessary, in order to take advantage of the countersinking, that the portion of the shank of the rivet which is next to the head, previously made, should itself have received this conicity; this part, being much less heated, not being able to mould itself, like the rest of the shank, to the conical sides of the opening (*).

(*) It will not be out of place to mention here, a fact in connection with the respective merits and demerits of drilling and punching, which has not hitherto, I believe, been brought forward : that, at any rate in some cases, holes *drilled* in a plate cannot be as accurately centred as those *punched*.

In the steel carriages, described and illustrated in Vol. II of this work, it was an object of great importance to have the holes in the diagonal bars forming the frame-work, made with such accuracy as to insure their perfect coincidence, and render all the bars required for the whole series of vehicles, interchangeable with each other.

I accordingly specified that the holes should be *drilled*, and by a special machine drilling all the holes at once. The result was however quite unsatisfactory; the holes did not coincide. Punching was therefore resorted to, with complete success. The explanation seemed to be, that the

70. *Plates with thickened edges. Helicoidal joints.* — The position of the rivets in many rows and the double covering plate, are not the only means of reducing the loss of strength along the lines of least resistance. This can be also attained by an extra thickness of the edges to be joined. But it is only on the longitudinal edges that the rolling can produce this thickening; it cannot thus be placed, in the cylindrical barrel, along the lines of greatest strain, that is to say parallel to the axis, excepting by bending the plates in a direction contrary to the rolling. The Midland Railway made use of plates with thickened edges from *Low-Moor*, the only works where they were made, and seems now to have given them up. The edges were thickened gradually, and for a breadth sufficiently large to include all the part turned up, and seemed better adapted for the connection of the cylindrical barrel with the fire-box and the smoke-box, than angle irons. The very excess of thickness rendered it still more necessary to employ metal of very good quality and great care and management in the operation of turning up the edges.

Instead of being directed along the lines of the greatest and smallest curvature, the two systems of rectangular joints may be helices, inclined at an angle of 45° to the axis. This arrangement, proposed by Mr. *Wright*, offers some advantages, among others, the equality of resistance of the two systems of lines of joints; but this has never appeared to compensate for the serious difficulties of construction involved.

71. *Welding.* It was not likely that endeavours to effect the continuity of the plates would fail to be made, especially for boilers, by taking advantage of the industrial property, *par excellence*, of iron, viz. its great facility for welding.

Mr. *Bertram* succeeded, by a process of his own, in joining together great lengths of plate by welding, and thereby obtaining resistances equal to and even exceeding that of the plate itself. The resistance with a weld of half thickness (Pl. I, *fig.* 23), rose to 104, the resistance of the full plate

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drill, not being fixed so solidly as the punch, and not having so well defined a centre of action, *wabbled*, and went out of the true centre of the hole, one side or the other.

The trials were made under the direction of Mr. *W. Wilson Hulse*, long the managing partner of Sir *Joseph Whitworth's* firm, whose well known ability and experience put the fact beyond any question.

I might mention that the holes came very clean and sharp from the punch, the metal being soft, and the bars thin: there being still of course in a certain degree, the peculiar shape of the hole, as described by M. *Couche* above.

(*Translator's note.*)

being represented by 100; it descends to 62, if the welding is done by superposition (*fig.* 24).

The boiler of the locomotive exhibited in 1867 from *Stephenson's* works, was formed of three cylindrical rings 4 feet in diameter, 3,87 feet long, with a thickness of 0,47 inch (for a pressure of 14 atmospheres), welded on to themselves, connected by covering hoops riveted to the rings, and welded on themselves in the same way. The circular edges were also thickened out at the covering plates; and the boiler thus very nearly satisfied the condition of equality of resistance. *Kitson's* engine, which figured in the same exhibition, had similarly, the longitudinal joints welded.

Mr. *Bertram's* process, after the experiments made at *Woolwich*, seemed destined to be practically applied, but is now given up. It is doubtful, in fact, whether a manipulation requiring a temperature high enough to alter the plates, can present as many guarantees as the purely mechanical operation of riveting, reducing the resistances in a known proportion; especially if the holes are drilled, or if, as many engineers think possible and easy, punching can be done so as to avoid all molecular alteration of the metal, or rendered unobjectionable by suitable annealing after the operation. If the suppression of the longitudinal riveting is carried out, it will probably be not by welding done afterwards, but by circular rolling, giving, as is regularly done for tires, finished cylindrical rings. However, the *Low-Moor* works, which had entered on that path, seems to have relinquished it; for industrial purposes, particularly for railways, the improvement was not considered important enough to warrant a notable rise in price.

72. Mr. *D. K. Clark* thus sums up the resistance of joints, connecting, under various conditions, plates 0,37 inch in thickness :

Resistance, full plate	100
Riveting by lapping, single row of rivets	60
Do. do. two rows of rivets	72
Do. cover plate single, two rows	65
Do. do. double do.	80
Do. welding by superposition	66
Do. do. end to end (Bertram's process)	100

Let us also take from the same author (*) the following results of the

(*) *Recent practice*, etc., page 4.

comparative experiments made at *Woolwich*, on the resistance of joints, welded by *Bertram's* process, or riveted. They have the advantage of showing clearly the influence of the thickness. In the case of superposition, the loss of resistance diminishes with the thickness. (60) Samples of good Staffordshire plate were operated on, chosen with the greatest care, so as to insure their identity, and eliminate, as much as possible, the accidental inequalities so difficult to avoid in experiments on the resistance of materials.

	THICKNESS OF THE PLATES.		
	0,50 inch	0,44 inch	0,37 inch
	Resistances.	Resistances.	Resistances.
Whole plate	100	100	100
Welding to half thickness (*fig.* 22)	»	106	102
Do. by superposition (*fig.* 23)	50	69	66
Lapping with single row, by hand; conical heads	40	50	60
Do. do. do. round heads	50	52	56
Do. do. by machine	40	54	52
Do. do. countersunk heads	44	50	52
Lapping with two rows : round heads	59	70	72
Do. do. : countersunk heads	53	72	69
Simple covering plate, two rows of rivets : countersunk heads	52	60	65

CHAPTER II

APPURTENANCES OF THE BOILER.

§ I. — Safety apparatus.

73. We shall dwell but slightly on these apparatus, common to all steam boilers. It is only necessary to allude here to those which are special to locomotives.

The regulation apparatus are : the safety valves, the manometers, the gauge glass, the rows of cocks, the spark-catcher in the smoke-box, and the ash-pan.

Valves. — Articles 5, 6 and 8, of the decree of the 25th January 1865 state :

" Each boiler is provided with two safety valves loaded so as to allow the steam to escape before its pressure reaches, or at least immediately it reaches, the maximum limit indicated by the *timbre*(*).

" Each of the valves offers a section, sufficient to maintain, by itself alone, whatever may be the activity of the fire, the steam in the boiler at a degree of pressure which in no way exceeds the above limit.

" The builder is free to distribute, if he prefers it, the total discharge section necessary for the two regulation valves, among a greater number of valves.

" Art. 6. Every boiler is provided with a manometer in good order, placed within sight of the stoker, arranged and graduated in such a manner as to indicate the effective pressure of the steam in the boiler.

" Art. 8. The level that the water should usually to be kept at in each boiler, ought to exceed by 4 inches at least the highest part of the flues, tubes, or flame-conduits."

Articles 23 and 26 render the preceding arrangements applicable to locomotive engines. The latter are thus, like stationary engines, set free from the rules of detail formerly drawn up for the construction of valves, by the Order of the 22nd May 1843 ; the object, that is to say the limitation to a fixed maximum number, to which the tension of the steam may reach, is alone meant to be obligatory; the decree leaves to every one the choice of the

(*) The timbre (art. 4) indicates the maximum effective pressure in kilogrammes on the square centimetre.

details of the execution of the valves, save the condition of employing at least two.

Notwithstanding this freedom, the old arrangements have been maintained, and if the diameters in use some years ago, were sufficient for relatively low pressures, they ought with greater reason to be sufficient with equality of heating surface, for the more considerable pressures admitted at the present day. They vary from 3,94 to 5,12 inches, this last figure applying to the most powerful engines, with a heating surface of about 2.000 square feet. Without doubt the gross heating surface, which, as we have seen, is far (19) from implying the power of evaporation, is not, any the more, a rational basis for the determination of the diameter of the valves. There is no question in this of a rigorous relation; all that is wanted is to give amply what is necessary, but which is not so easy as sometimes supposed.

Their imperfections. — Locomotive valves only differ from those of stationary boilers by the substitution of a spring in place of the weight for loading the lever. This is almost the necessary consequence of the state of movement. On account of the vibrations, not concordant, of the boiler and an independent weight, the valves would blow even under a pressure of steam very inferior to the statical load, and their indications would be wrong. Their function being, or at least intended to be, not to make the pressure known at each instant, that is the duty of the manometer, but to limit it by giving an escape to the steam as soon as the legal maximum is reached. It is on this maximum that they should be regulated in order to blow off then only.

Weights have however been applied, for example, by *Egerstorf* at *Linden* near *Hanover*, who gave it the form of a lens suspended to the lever by a small *Baillie* spring; but it was rightly considered necessary to guide the weight, which was done by two vertical rods fixed to the boiler, and passing without friction through two cylindrical holes in the lens; but it was sufficient for one of the rods to be slightly put out of line, wilfully or not, to deprive the weight of its freedom of action.

But abstraction made of all faults of construction or of maintenance, this arrangement does not completely attain the required object.

" Experience has shown ", said the instruction attached to the Order of 1843, " that a single valve, the orifice of which has a diameter determined by the empirical formula

$$d = 2{,}6\sqrt{\frac{S}{n - 0{,}412}}$$

is sufficient to discharge all the steam which may form in the boiler, *at the tension of* n *atmospheres*, under the influence of the most active fire."

And art. 5 of the decree of 1865, reproduced farther back, without stipulating the diameter, prescribes :

"That each of the valves shall suffice *by itself, whatever may be the activity of the fire, to maintain the steam in the boiler at a pressure which in no case exceeds that of the timbre.*"

If this were so, the valve would be irreproachable; it would be what it ought to be, an automatic apparatus, limiting the pressure at the desired point. But the fact expressed by the first passage underlined is not exact, and the condition prescribed by the second is not fulfilled. The valve, if it acts properly, lifts as soon as the prescribed tension is reached; but it does not prevent this tension continuing to increase more or less. As soon as the valve is lifted, the pressure on the unit of surface, exerted on it by the steam rushing out, is inferior to the statical pressure which exists in the boiler at a sufficient distance from the opening; and in order that this opening may be kept free enough to let out at each instant the steam produced, it is necessary that the excess of internal pressure on the pressure, equal to the external load, which acts on the valve and keeps it in equilibrium, should be more or less great, and frequently considerable. The consequence of this fact would be, that in order to limit the tension to n atmospheres with certainty, the load of the valve must be regulated below this number, but by how much? or the diameter or the number of valves increased; but again by how much, and without considering difficulties of construction?

The imperfection of the valve thus arises from the fact that, on account of the rapid relative decrease of the pressure exerted on it by the steam, the moment it lifts, the rise is very slight, and consequently the effective orifice of escape very small. In order that this orifice, that is to say the convex surface of the cylinder, having for height the rise l, and for base the area of the valve, might be equal to the latter, it would be necessary to have : $\pi\, d\, l = \frac{1}{4}\pi d^2$ or $\frac{l}{d} = \frac{1}{4}$, a value which this ratio is always far from attaining, and the farther off the larger the valve, so that it is very far from being equivalent to a free opening of the same diameter as it self. P being the weight of the steam to be supplied per second, δ its specific weight, $U = \frac{P}{\delta}$ its volume, v its theoretical velocity and mv its real velo-

city of discharge, the *effective* section of discharge ought to be $\frac{U}{mv}$, and the diameter of the valve : $d = \frac{U}{mv\pi l}$. With ordinary arrangements, l does not exceed 0,10 inch, 0,12 at the most (this last figure was prescribed by the *technische Vereinbarungen*, 1871. Undoubtedly it is seldom reached with the large orifices and rigid springs actually used.

The load of the valve should diminish as its rise increases; under the action of the spring applied to locomotives, this load increases, on the contrary, with the rise, and the normal pressure is so much the more exceeded.

74. The rising of the valve has the effect, it is true, of increasing the surface upon which the steam acts. But it is more exact to say, that the area of this surface before the valve rises, is often not rightly known. It is well defined, if the zones of contact of the valve and its seat are truly ground, and exactly fit, the one on the other; but by no means so if the steam can penetrate between them. In order to render at the same time the contact easier, and more likely, and to limit the possible deviations from the real surface, the zone of contact is made as narrow as is permitted by the load which it has to support. Its breadth ought not to exceed $\frac{1}{30}$th of the diameter of the orifice, and in absolute value 0,079 inch.

The serious nature of these imperfections must not however be exaggerated. The driver ought to make sure that the valves are acting properly; as soon as they blow, he should not remain passive. Warned that the limit of pressure is not only reached, but exceeded, guided also by the exact indications of the manometer, he ought to act in consequence, and take steps to bring things immediately back within the regulation, that is to say, to get the valves back to their seat, by a reduction of the internal pressure; and for that, sufficient means are available, including that which consists in unscrewing the valves to increase their rise and the discharge. If on account of the manner in which it is loaded, the locomotive valve is more imperfect than that of stationary engines, the insufficiency of its automatic action is, on the whole, less disadvantageous for engines which are so closely looked after.

The difficulty experienced in providing large *effective* orifices for the escape of the steam, is, however, not a matter to be greatly regretted. A certain excess of pressure, provided it be contained within proper limits (a thing always easy to manage), presents less inconvenience and danger than

the abrupt opening of large free orifices, giving to the steam, indeed to the water itself, great velocities, and thus subjecting the sides of the boiler to violent shocks. In this way is explained the abrupt opening of the valves, or of one of them, which is sometimes observed with certain relative positions of the valves and of the regulator, when the latter is opened suddenly and too far.

75. *Stops*. — In order that the driver may not adjust the balances for a pressure higher than the normal figure, a stop fixed on the screwed rod which transmits the tension of the spiral spring to the lever, butts against the lever, and prevents any increase of the tension being given to the spring by turning the screw. This ring, fixed by a pin, cannot be displaced, but the driver might clip it on the top; so on the Northern of France the precaution was taken of cutting a mark to show its height.

The employment of stops or *rings* is general in France, where it is prescribed by a decision of the 15th June 1849. One company however, that of the *Mediterranean*, applied for and obtained in 1864, authority to suppress them. In this particular case, there was little objection. It is of small consequence depriving drivers of the power of exceeding, by means of the nut, the regulation tension of the spring, if the very arrangement of the safety-apparatus offers them the most simple and inviting means of closing the valves when they please, and doing away instantaneously with every sign of this grave infraction, especially if both are placed directly to their hand; a position preferable in some respects, in spite of the annoyance to the driver when they blow off.

The detail of construction to which we allude, is the continuation of the short lever by a straight or curved appendage, which, with a slight inclination of the lever, comes down on the edge or on the bottom of the cap (II, Pl. XXXIX, XLIII, etc.). A small wedge put in under this spur, is sufficient to keep down the valve; it also much the same with respect to the guides often applied to the levers, when the fork is closed above (Pl. XLVI, etc.). With means which it is so easy to abuse, it is indifferent whether another exists or not. They have one object, without doubt, viz. to keep the valve in its place, as otherwise if the spring broke it would be shot out like a projectile; but this is an accident which ought never to happen, and in fact never does. To prohibit it by a special measure, would be well, provided the precaution were only useless; but it is a mistake if the precaution is dangerous. On most railways, attention is rightly given above every thing, to doing away with whatever can facilitate closing the valves, and the breakage of a spring the chance of which

is so slight, is neglected; and this chance may be still further reduced by adopting, as on the Northern of France and *Orléans* lines, for example, two springs instead of one.

It is unnecessary to say that the reason for suppressing the ring, which has just been alluded to, is not that by which the *Lyon* Company supported its application; the immediate consequence would have been the suppression of the spur, and that was adhered to. The argument brought forward and, not without reason, is that the ring itself offers to drivers an indirect means of overloading the valves. By screwing the nut home, the lever and the screwed rod become one, and may, especially with the rod a little out of shape, develop a very notable additional resistance. It is further added, that in case of the valve being out of order, the driver may be under the necessity of exceeding a little the regulation limit. This second objection scarcely bears investigation. What is an *absolute* maximum, which may be exceeded under a pretext always easy to find? But in the first objection there is a certain force, although most engineers do not consider it worthy of their attention.

Arrangement of the valve-levers on the Orléans lines. — It is besides easy to prevent the driver realizing this invariability of the angle of the lever and the rod. It suffices for the two pieces, between which the lever is tightened, to be applied on the bearing by knife edges; then, whatever may be the amount of tightening, the position is always the same as if the lever and the rod were connected by a free joint in their common plane. It is so done on the *Orléans* line; *figs.* 1 to 4, Pl. IV, represent the arrangements adopted. Between the nut E (on which is a checknut q, to prevent unscrewing by the effect of the vibrations), and the lever terminated by an elongated ring, a piece of steel a, a is let in, which rests on a notch in the second, by two knife edges c, c. The tube t, t in one piece with the rod θ, is terminated by two sides, the edges of which butt against the lower face of the lever. Thus disappears whatever objection there may to the ring, as ordinarily applied.

But neither ring nor regulation can prevent drivers occasionally overloading the valves, for example, by pressing on the lever, to prevent the valves blowing off when going up inclines; nor can anything convince them, as it has often been tried, that this practice can be of no immediate use.

76. *Closing the valves.* — It is however a matter of less importance to provide against this transient abuse, than against the prolonged closing of the valves by tying down or otherwise. But a driver who habitually does this, cannot long escape the watchful eye of a vigilant foreman.

" Some drivers ", says an instruction (No 93) of the *Mediterranean* locomotive department " content themselves with tightening the balances beyond the tension indicated by the stamp. This practice is already the source of serious disadvantages. " (Implicit acknowledgment of the utility of the ring judiciously applied). " Without doubt the apparatus are tested to, and do resist, pressure considerably above that of the stamp. But in work, when at a heat already intense, they do not resist so well as when cold. Besides after a certain length of service, and even in consequence of the testing pressure, the metal may be affected. Stays, tie-rods may be broken, and the excess of pressure thus cause leaks, fractures, deformations, which may be the source of serious dangers, and which, in any case, involve considerable expense in repairs. "

" Drivers suppose that in thus forcing the pressure, they realise an appreciable economy of fuel. This was true formerly, when the normal pressures were very low. *It is an error now, because the normal pressures have reached the limit which corresponds to the best use of the fuel*, satisfying besides all the requirements of the service. "

Nothing can be more judicious than to put drivers on their guard against excess of pressure and to make them comprehend, that independently of the danger of explosion, they can only lose by pushing their boilers too far, as they produce leaks and require their engines to be sent into the sheds. But to pretend (and that in 1866, the date of the preceding instruction) that the economy of fuel and the power of the engine had nothing more to gain from an elevation of the pressure, that the maximum limit of the useful effect of the fuel had then been reached, was going a little too far. The best proof is, that the normal pressures have been greatly raised since that time, and that they have still a tendency to rise. In the face of this fact, to tell the drivers that it is useless to increase the pressure, is to have little chance of convincing them. What they should be told, is, that the boilers in which this increase applies are constructed and tested accordingly; that in that case it is at the same time useful and without danger, while it is, as the instruction says " foolish " to apply it to boilers which are in no way made to bear it.

As to the drivers being the first victims of an explosion, as pointed out by a service order of the Eastern of France, we know how little they care for that, whether it be that habit has deadened their fear of danger, or whether they experience a sort of satisfaction in braving it. It is by strict supervision and by disciplinary measures, with reference not only to the drivers, but also their foremen, when they do not see what they ought to see, that the abuse can be repressed.

" Other drivers ", the instruction cited above of the *Mediterranean* line, justly continues, " completely suppress the play of the valves, by means producing absolute closing. The pressure of the boiler is thus no longer limited, except by the ratio of the expenditure of the steam to its production. It is sufficient for the expenditure to diminish for

a few minutes on any account, such as stopping, slackening, descending an incline, to cause the pressure to augment indefinitely, without other possible limit than the explosion of the apparatus."

77. *Various improvements.* — Mr. *Ramsbottom* devised a plan to connect two valves together by coupling a single spring to the middle of a bar loading them both, and upon the continuation of which at A (Pl. I, *fig.* 6, and Pl. II, *fig.* 4), the driver can act to insure their working properly, and to detach them from their seat. Whether he raises or lowers this lever, he can only increase the load on one of the valves, by decreasing the load on the other. But this arrangement requires, with ordinary diameters, a very powerful spring, as it must have a tension equal to the sum of the loads on the two valves. This leads to the employment of four valves, an indispensable proceeding when one is required close to the driver, as is often the case, and another farther off, for example, on a dome, towards the front or middle of the engine.

Mr. *Baillie* also applied the load directly, and found here an application of his *volute* springs. In order to give the valve a large diameter, the pedestal which carries it is very much widened out towards the top. Sometimes it is even the cover of the man-hole itself which acts as a valve (Pl. III, *fig.* 11); but the use of this method has not extended. Admitting a volute spring to be applied to one of the valves, placed beyond the reach of the driver, it is always desirable that the other should be loaded by means of a lever, by which the driver can more easily ascertain if it works properly. The load applied directly, has besides no advantage of itself over the spring acting by the intermedium of a lever. The play of the springs, instead of being much greater than the rise of the valve, is only equal to it; but to this reduced play corresponds the same proportional increase in the initial tension of the spring.

To MM. *Lemonnier* and *Vallée*(*), foremen on the *Orléans* line, the idea occurred of interposing a double joint bent back on itself between the screwed rod and the spring (Pl. IV, *figs.* 5, 6 and 7). This straightens itself as soon as the regulation tension is a little exceeded, by setting free a piece *t*, which keeps it doubled over till then, and allows the lever and the valve to lift up fully, and thus gives even with valves of reduced diameter, a large real orifice of escape; but at the same time a bad use should not be made of this increase (75). The idea is ingenious, but the mechanism is delicate; and after having had a certain amount of success, it is nearly given up.

(*) *Annales des mines*, 5th series, vol. I page 337, 1852.

Figures 8 and 9 (Pl. IV) represent an apparatus which is not without analogy to the preceding, although the principle is different. The method of connection of the lever and screwed rod θ, has no longer the effect of abruptly reducing, at a given moment, the load transmitted by the spring, but gradually reducing, as fast as the lever rises, the *effective* leverage with which it acts. The load on the valve is thus rendered nearly constant. As long as the valve is on its seat, its effort has for leverage O P (*fig.* 9). As soon as it rises, the cranked lever *m n o* (*fig.* 8) takes the position *m' n' o'* (*fig.* 9), the whole system inclines, turning round the point *a*, and the leverage of the spring is reduced to O P' (*fig.* 9). Suitably regulated, the reduction of the leverage compensates for the increase of the tension.

This regulation is affected by means of a screw *v*, which allows the point to be varied at which the double spindle *t* takes the cranked lever, and consequently the inclinations taken at a given rise, by this lever and the spring T.

The lower nut *e* (*figs.* 8 and 9) serves to give the latter the initial tension corresponding to the stamp.

This apparatus, due to M. *Meggenhofen*, received in 1851 the prize founded by the *Société Industrielle* of Lower Austria, and is still at times adopted. An application of it is to be seen on Pl. LIII (engine of the *Moscow* and *Koursk* line) and the *Alsace* Society (*Kœchlin's* old firm), for example, has applied it to engines recently constructed for the *Alsace-Lorraine* lines, and concurrently with a pair of *Ramsbottom's* valves; the latter placed on the dome, and *Meggenhofen's* valve on the fire-box.

Mr. *Naylor* effects the same thing, by an arrangement also very ingenious; the principle of the solution is still carried out by varying the ratio of the leverage; instead of diminishing that of the spring, Mr. *Naylor* increases that of the valve, in proportion as its rise increases.

In order to carry out this idea, Mr. *Naylor* replaces the straight lever by a bent one (Pl. IV, *fig.* 17). When the valve is down on its seat, the arm which presses it is horizontal, and the other to which the spring is coupled by a stirrup *e*, is inclined. If the valve rises, the distances between the respective points of application of the efforts of the valve and of the spring and the axis of the lever diminish, but very unequally; the one by a quantity which may be neglected, the other a great deal.

Let *a* and *b* be the lengths of the two arms, ω the inclination of the second to the vertical, the ratio of these distances is, before the rise of the valves,

$$K = \frac{a}{b \sin \omega}.$$

For a rise $a \sin \alpha$ of the valve, corresponding to a rotation α of the lever, this ratio becomes: $K' = \frac{a \cos \alpha}{b \sin (\omega - \alpha)}$.

For $a = 2{,}5$ inches, $b = 3{,}05$ inches, $\omega = 35°$, and for a rise of 1,57 inch, $\alpha = 3° 39'$ whence $K = 1{,}43$, and $K' = 1{,}57$, that is to say, an increase of 0,14 or 9,8 per cent.

The spring is regulated in such a way that the increase in its tension may be compensated by the diminution of its effective leverage. The moment is thus constant; and so is that of the moment of the load of the valve, which is equal to it, and consequently to the load itself, seeing that the leverage does not perceptibly change when the line is inclined a little.

Instead of being much greater than that of the valve, as in the ordinary apparatus, the effective leverage of the spring is, on the contrary, smaller, even before any rise ($b \sin \omega$); the tension of the spring is thus greater than the load; and in order not to exaggerate the first, the diameter of the valves is necessarily very reduced; but its smallness is compensated by its greater rise, so that it is not necessary to multiply the number of valves. Mr. *Naylor* concludes from his observations that two valves, two inches in diameter, (section, 3,14 square inches), with a rise of 0,16 inch, which is easily obtained by the arrangement described, and giving for each an effective discharge section of 1 square inch, are more effective than two ordinary valves 4,85 inches in diameter; and that they maintain for example in the boilers of the most powerful locomotives, the pressure at the limit of 8 atmos., while with the others, the pressure rises 1,36 atmos., even without forcing.

However, M. *Schröder*, who has noted on the Austrian State Railway the progress of the pressures in a boiler in which the fire was actively kept up, and to which valves of different systems were applied, came to the opinion, that Mr. *Naylor's* valve does not present advantages sufficiently marked to warrant its being adopted.

Kitson's valve is very analogous to the preceding one. The lever is also bent, and the rise of the valve has the effect of increasing its leverage, instead of diminishing that of the spring.

Finally, a spring sufficiently long, is generally considered sufficient, if a slight increase of tension corresponds to the necessary rise for the discharge of the steam. The excess of tension is thus limited; it ought moreover to be only temporary in every locomotive properly driven; as the driver has plenty of means for lowering the pressure. The graduation is continued to a quarter above the effective regulation pressure.

78. *Position of the valves.* — It is sufficient to glance over the plates, in order to see how much the position of the valves varies. When there is a steam dome, as is ordinarily the case, it always receives one of the valves, and sometimes both; thus avoiding a special opening into the boiler. We must not however keep out of mind the fact, that openings are very useful for cleaning, and that the essential point is to strengthen them thorougly (37). The dome also allows of a great length being given to the springs. As M. *Krauss's* boilers have no domes, the builder was induced to raise the lever of the valve placed towards the front of the boiler; but this has the effect of rendering it unsteady and subject to jerking, and causes it to exert oblique pressures on the valve, the spring at the same time being of insufficient length : the arrangement (II, Pl. XXI, *fig.* 1) is therefore faulty.

79. *Manometers.* — The compressed air manometer having well-known drawbacks, which increase with the pressure, divers attempts have been made to render the principle of the open air manometer suitable to locomotives. These resulted in two arrangements, M. *Richard's*, and M. *Galy-Cazalat's* which took its maker's name M. *Journeux*. The first was equivalent to a series of manometers communicating with each other. The depression of each of them measured a fraction of the pressure. The second reduced the height of the mercurial column, by causing its acting on a far wider basis than the one submitted to the pressure of the steam.

But these apparatus which are difficult to keep up have disappeared. Locomotives nowadays have nothing but different varieties of metallic manometers, all founded on the elastic deformations of a thin metallic plate, under the influence of the pressure. In M. *Bourdon's* apparatus (Pl. IV, *fig.* 13), which is the most used in France, the blade is a curved tube of elliptical section fixed at one end and free at the other; sometimes the form, the length, and the cross-section are such that the displacements of the free extremity are ample enough to give the direct measurements of the corresponding pressures; sometimes the length of the tube is reduced and the travel of the index increased by coupling with the help of a connecting-rod the free end of the blade to the small arm of a needle. In others, more adopted in Germany, the elastic blade is a sort of circular membrane in steel, fastened by its edge and provided with circular corrugations which render it more sensible, and amplify the displacements of its centre, but not sufficiently to avoid further amplification by a combination of levers.

These apparatus are graduated by comparison with an open air manometer. If the needle comes back at one atmosphere (or at 0 according to

the starting point), when the steam has ceased to act, the presumption is that the instrument has remained nearly exact throughout the whole range of the scale. If the needle does not come back thereto the driver must of course take into account this displacement of the zero point. Rigorously speaking, it would be sufficient to bring back the needle to that point; but as the elasticity would then be altered, a new graduation by comparison with the open air manometer should always be made as soon as possible.

The tube of *Bourdon's* manometer must not be in contact with the steam, as the high temperature might alter its elasticity. The tube which communicates with the boiler is thus fitted with a double elbow filled with water, by which the pressure is transmitted to the tube. But should this elbow happen to freeze, the water of course stops the action of the instrument and may even put it out of order.

80. *Maximum manometers.* — It is easy to arrange manometers in such a way that they mark, as maximum and minimum thermometers do, the indication of the highest pressure reached in the course of a given period. *Figs.* 10 to 12 (Pl. IV) represent the application of the principle to a manometer, on *Dedieu's* system, which has been employed on the Eastern of France. We shall describe it in order to bring out the simplicity of the tubular manometer of M. *Bourdon*, compared with those apparatus which are founded on the small deformations of an elastic plate.

The steam arriving in the reservoir X (section, *fig.* 12) presses against a circular india rubber membrane KK, covered with a very thin sheet of copper, and on which is applied a copper disc D taking at its middle the plate of steel CC fixed at the two ends by the screws UU. The indications of this instrument are shown by the deflections, amplified, of the plate CC. The lever FO which rests on the plate by the butting screw V, rises with the latter, causes a lever OP to take positions O'P', O"P" and the sector S to which the lever OP is fixed at P, turn through corresponding angles. The indicating needle α is fixed on the axis Q of the sector.

When the pressure decreases, the hand follows it by the action of the spring L applied against a stud on the disc. The screw V allows the apparatus to be regulated, when any part is out of order. The indication of the maximum of pressure requires no other addition than that of a small hand β fixed on a disc, the axis of which E (*fig.* 10) enveloping that of the large hand, is independent thereof. A rack R in gear with very fine teeth occupying a portion of the edge of the disc, keeps the needle β in the position

which corresponds to the stamp; there is in fact no interest in knowing what takes place below that limit.

When that is reached, the large hand α is exactly over the little one; when it is passed over, the first takes on the second by means of the stud e and the ratchet maintains it in that extreme position, as long as it is not pushed farther.

On the *Lyons* Railway, the maximum hand has been applied by a mechanician, M. *Peschel*, to M. *Bourdon's* much simpler manometer. This hand b has a continuation b' which is let into the notches c, c, c; it is thus maintained in the extreme position which the main hand α has caused it to take when the latter comes back.

It is necessary: 1st, that the driver should not be able to open the instrument so as to set free the hand from the teeth or the stopping notches; 2nd, that he may not be able, by shutting the communicating cock between the boiler and the manometer, to put the instrument out of working.

To lock the lid would be idle; drivers very well know how in such a case to do without the key, which is of course kept in the hands of the superintendent; but it is easy to seal the instrument; and when an engine comes into the shed with the index pointing to a prohibited pressure, the superintendent has to break the seal, return the index, and seal the box anew.

The second point, the suppression of the cock, might raise some objections; although the breakage of the elastic tube is very rare, it might take place, and require the instrument to be shut off from the boiler. But as the use of the cock is very rarely required, there could be no objection to seal it also; in the case of the seal being broken, the driver would have to justify the grounds of the breakage.

In 1865, it was decided that all the engines of the Eastern of France should be provided with maximum manometers. In some of them the needle acted ostensibly, as in the *Dedieu* manometer; in the others it was concealed behind the dial, and the superintendents could only make an inspection by opening the box.

These manometers have been objected to, because they indicate only the maximum reached; whether it were only once, or several times, and for a greater or less period, the indication is the same. So that as long as the driver knows that he will be betrayed by this mute witness, he has no further interest in caring about the pressure of the steam, and might even think well to force it, provided he did not exceed the limit already reached.

Without doubt the instrument does not give a complete indication of what takes place, and it would be more efficient if it did so. Such as it is, how-

ever, it still offers a certain guarantee; and the abuse of pressure which the driver might still commit in spite of the indicating hand, he would commit far more without it; as he would then be sure of impunity, unless taken in the act. The objection has been made, that the addition of the maximum hand would be a continual infliction on the shed foreman, who would have to verify the state of the manometer every time the engine came back to the shed. This is in no way necessary; the proof of the infraction, whether verified on the spot or a little later, is sufficient, as the driver must always be subject to the consequences. If arrangements of this kind have fallen by degrees out of use, it is not by any means that they are recognised as useless, but in consequence of a sort of mutual understanding. Means of control, naturally objectionable to those who undergo them, are at times hardly less liked by those who have to put them in force. Both agree to let an apparatus slide into oblivion which for the one is a denunciator, for the others a source of trouble.

81. *Increase of the pressure while standing, the valves having the regulation load, and by the sole fact of keeping up the fire.* — Useful during running, the indication of the maximum pressure would be still more so while the engine is standing. The voluntary exaggerations during running are sometimes less to be feared than the accidental exaggerations which may be produced, from want of attention, in engines when standing. The cylinders no longer taking steam, the evaporation is often still active enough, although the draught may be almost nothing, for the pressure to rise rapidly, in spite of the lifting of the valves, above the regulation point, especially when the *blower* has been opened to prevent the production of smoke. It is known besides, and I have frequently verified it, that valves regulated to 8 atmospheres, for example, and which during running *start* exactly at that pressure, do not leave their seat until 9 and even $9\frac{1}{2}$ atmospheres are reached, when the engine is standing. The shake produced by a slight shock, such as the tap of a hammer on the boiler, is however sufficient to set them free.

In connection with the explosion of *la Turquie* engine, I made, with M. *Lamé-Fleury*, ingénieur des mines, some observations on this progressive rise of the pressure in an engine at rest.

Engine 0,412 of the Eastern of France. Stamp, 7 atmospheres.

The pressure being at 7 atmospheres (indication given by one of *Desbordes's* manometers verified by the standard manometer) and the valves well regulated, the engine was brought into the shed. The fire was lighted, the chimney without cover, the con-

ditions were followed of an engine drawing a goods train on a siding, the driver of which held himself in readness to start at the first signal:

At 1 o'clock, pressure :		7	atmospheres.	
do 1h5′	do	7,9	do	
do 1h10′	do	9	do	
do 1h12′	do	»	do	the pressure continuing to rise, the valves were unscrewed.
do 1h15′	do	8,6	do	
do 1h20′	do	7,5	do	valves were screwed down again to 7 atms.
do 1h25′	do	7,4	do	
do 1h30′	do	7,7	do	
do 1h35′	do	7,8	do	the grate being almost empty, a few shovel-fulls of coal were added.
do 1h40′	do	8,1	do	
do 1h45′	do	9	do	

The fuel was *Saarbrücke* coal, easily inflammable. With coke made from the same coal, the pressure rose, under the same conditions, but leaving the valves always regulated at 7 atmospheres, from 5.5 atm. to 8.6 atm. in 45 minutes; the effect is thus the same, but slower.

There may thus be produced while standing, by the simple keeping up of the fire, a dangerous rise of pressure, which the valves, under the regulation load, are powerless to prevent; at least with easily combustible coal. The consequence should be that the valves ought to have two regulation loads, the one for running, the other at a less pressure for standing. But no general rule can be drawn up with regard to this; it ought to vary according to the nature of the fuel.

On the Eastern of France line, the driver's regulations have:

"Art. 41. If the standing lasts longer than an hour, or if the engine is in reserve, the valve-balances should be let down two atmospheres.

"Severe penalties will be inflicted on drivers and stokers convicted of not having faithfully executed this prescription."

If the measure is really necessary, the length of time standing, from which it becomes obligatory, is evidently much too great. Besides, when a goods train is detained in a goods shed or on a siding, it is often impossible to foresee how long the stoppage will last, and in doubt, the driver avoids letting his pressure fall. He does not cover the chimney and refills his grate. The insufficient description of the article quoted has however up to a certain point its correction in article 42, thus drawn up:

"In stations where they have to stand, the driver and the fireman must not be

absent together, unless there is some one specially in charge of the running engines, They ought, in any case, to be back at least half an hour before the hour of departure, and to point out where they can be found if required.

"A lighted engine ought never to be left by itself. Every infraction of this rule is severely punished."

And yet the imperative prescription of the second paragraph is somewhat done away with by the two first.

Moreover the only absolute obligation is that the regulation pressure be not exceeded. The unscrewing of the balances while standing is only a measure of detail, one of the means of execution, to which every one is free to resort or not. On the *Orleans* line, for example, the necessity for prescribing it has not been felt. On the Northern of France, it is practised in virtue not of a regulation, but of a simple recommendation, to the execution of which, however, the locomotive staff strictly sees. Nothing is stated as to the minimum of standing which renders the measure necessary. The driver ought to let down his pressure to five atmospheres, whenever he foresees the standing will be long enough for him to get up his pressure again.

It is looked upon as sufficient to let down a single valve. The working of the ordinary small nuts being often rather hard, the carrying regulation the into effect has been rendered easier, on Northern of France, by providing one of the valves with a little hand wheel, instead of a simple nut. (II, Pl. XXXII, *fig.* 1, left hand valve.)

The maximum manometer would be a real guarantee against excess of pressure, whether at the will of the driver during running, or from a want of attention during prolonged stoppages.

It is less safety than economy which comes into play in this case, for locomotive explosions are extremely rare. The accidental and limited excesses of pressure strain the boilers greatly, the fire-boxes especially, and thus contribute for a great deal, to the expenses of maintenance; the companies know this, and they try to prevent it by strict supervision. They would consult their interests more still by trying to turn also automatic indications to account.

82. *Gauge glass. — Rows of cocks.* — The glass tube, always indispensable and which it would be necessary to accept even had its disadvantages, has really none. Before the development of the railway-system, it was often very difficult in the case of stationary boilers, to insure the carrying out of the regulation concerning the water-level tube. To justify its

being absent, the stokers appealed to the frequency of breakages which were inevitable, they said, under the action of simple currents of air. Now these tubes stand very well on locomotives; where however they are exposed to the air and the rain. They resist because they are of well annealed glass, are thick enough, and especially because by careful fitting they can slide freely in their packings. It has sometimes been considered desirable to protect the tube against shocks and against abrupt variations of the external temperature, either by wire gauze, or by enveloping it with another tube large enough to leave between them a layer of air, say $\frac{1}{5}$ th of an inch. But these precautions do not appear to be necessary; and have besides the disadvantage of rendering the level of the water less visible. An arrangement of packing has been proposed by which the communication with the boiler should close automatically in case of the breakage of the glass tube. But cocks worked by hand would always be necessary; and if there really were anything to be done in the matter, it would be to connect them in such a manner that one single movement should shut the two of them together.

The driver ought to blow off frequently in order to prevent the obstruction of the communications of the tube with the boiler; he ought also to be on his guard against the effects of the general increase of bulk of the water produced by the ebullition, and the lowering of the level of the water produced by draught when opening the regulator, effects which cease on its being closed.

The three cocks one above the other, are always indispensable in order to supplement the gauge glass, in case of that breaking, but only replace it imperfectly. They have to be manipulated; and it is not very easy, especially at night, to ascertain whether a cock is giving water or steam. Independently of the evaporation into the open air, the jet which rushes out from a boiler through an opening made below the level of the water, is always mixed with steam, formed, as results from the principals of thermodynamics, during the rush of the water towards the opening, and in greater proportion, the higher the pressure.

83. *Fusible plug in the roof of the inside box.* — This appendage of which we have already spoken (II, 275), ought to be classed among safety-apparatus. Its object is, as we know, to prevent burning, which would result from the lowering of the level of the water below the roof for any length of time. In order to fulfil this preventive part, the fusible core should be

let in to a copper plug, screwed into the plate, and should rise a little above the level of the roof, in order to be out of the water first. If the lowering of the water level is the consequence of the breakage of one of the tubes, the lead plug does not melt, as the water running in through the broken tube puts out the fire. In this way, the presence of the plug does not involve the stoppage of the engine, this of course only happens, without reference to the lead plug, when the tube cannot be stopped and kept so (24).

The lead-plug sometimes comes out (and consequently the fire becomes extinguished) without the lowering of the level of the water below the roof; this is from the plug, having gone out of shape, losing its lap and ending by being driven out by the pressure. Without involving the driver in such responsibility as if it were melted by the exposure of the roof, this accident shows him in fault, by having neglected to inform himself of the state of the lead plug.

It happens also at times that the plug melts without letting steam pass through; this is because the tartar has got thick and consistent enough to keep the opening obstructed. The fusion of the plug may even take place, with or without steam passing, and although the roof may be still covered with plenty of water, on account of the thickness of the deposits, whether adherent or not.

Some drivers, instead of seeing in the fusible plug a guarantee against the burning of the roof, look particularly on it as a witness that can disclose gross negligence on their part; they thus refrain from asking for one when wanted (at times the copper plug is in its place, but not bored out, or indeed the lead may have been replaced by an infusible metal).

These are facts which ought not to escape a careful foreman long; and drivers doing such things must reckon on very slack superintendence on the part of the foreman, whose duty it is to look very minutely into these matters, and at least once a month.

The opening ought not to be too small. Far from putting out or checking the fire, a jet of steam may on the contrary help to increase the combustion; and the fire may be seen to go from a red to a white heat. This is a fact which has been long known, and of which advantage has been tried to be taken. The decomposition of the steam and the combinations of its elements with those of the fuel, give no gain of heat, but they lengthen the flame, so that the injection of a certain quantity of steam may be advantageous in the case of certain fuels.

Too reduced a diameter would thus go directly against the objet of the fusible plug, which is to lower the temperature in the fire-box. Its minimum

diameter is ordinarily from 0,28 to 0,32 inch, its shape longways being at the same time variable: sometimes simply conical, at other times with either one or two swellings.

In the engines of the *Orleans* line, the number of the fusible plugs is carried to three; one in the diametral plane, and one on each side, the latter coming into play in the case where one side of the roof might be uncovered on account of the transversal slope of the permanent way (I, 200).

84. *Means of preventing incandescent pieces of fuel from being thrown out: a, spark-catcher in the smoke box; b, ash-pan.* — The locomotive presents some dangers of fire, both to the neighbourhood and to the train which it is drawing (II, 11, 64).

It may allow fragments in combustion to escape, both through the chimney and through the grate.

Far from increasing this danger, the almost general substitution of coal for coke has on the contrary reduced it. The amount of cinders through the chimney is in the direct ratio of the activity of the draught, that is to say of the reduction of the blast pipe opening, which is much less with coal, both because it is more inflammable, and because there is a much less thickness of it on the grate. As regards the grate, the bars being closer together the finer the fuel, the bulk of the pieces that can pass through is of course so much less

If it were objected that pieces of coke are much quicker extinguished than pieces of coal, a sufficient answer would be that the pieces in contact with the grate, that is to say, those that fall through, having been on fire for a certain time are very nearly coke themselves.

In France, the regulation order of the 15th November 1846 states (art. 11):

"Locomotives ought to be provided with apparatus having for object to catch the coke falling from the grate, and to prevent sparks passing out of the chimney."

In principle, the expedient adopted is always the same:

1st. In the smoke-box, a horizontal grating, with cross wires, placed above the tubes (II, pls. XXXVI, XXXIX, L, *et cætera*);

2nd. Under the fire grate, an ash-pan, formed, in its complete state of development, of a sheet iron case, having in front and behind, movable sides, which allow the driver to increase or diminish the draught as much during forward running as backward, and to poke the fire from below, if the arrangement of the grate permits (II, pls. XIX, XXI, *fig.* 1, Pl. XXIX, XXX, etc.).

For certain types of engine, the bottom of the ash-pan was a serious obstacle. With fire-boxes going low down and boilers little raised above the permanent way, like *Crampton's* for example, or for slow goods engines, consequently with small wheels, the vertical section of the air-opening was insufficient; moreover, for very long fire-boxes, this bottom interfered with cleaning out the grate; lastly, it accelerated the destruction of the bars, and rendered the *fire-dropper* (14) much less efficient.

Closed ash-pan. The closed ash-pan has always, however, been in general use in England, but this is because much importance has never been attached there to the lowering of the centre of gravity of the boiler (II, 249); and as the ash-pan is considered there much less a safety apparatus than the normal means of moderating or indeed completely closing the draught, they always managed to give it the necessary height. We should at once add that with the pure English fuel, which is easily inflammable, and rarely requires the grate to be cleared out, powerful means of moderating the draught are indispensable.

In France, in the engines cited just now, they were led to cut deeply into the bottom towards the front, and often also into the hind plate. Thus modified, the ash-pan failed in its object the more as there soon formed on the part of the bottom which was retained a deposit of cinders and coal dust, down the slope of which the pieces rolled out on to the line.

The insufficiency of the front section of the air-opening, and the rapid destruction of the bars, were sought to be obviated by replacing the side plates and the hind one, by a grate with vertical bars. But this modification, which was also insufficient for the draught, would only have been admissible by making the ash-pan acting as a safely apparatus, and bringing the bars much too close together.

The drawback was more serious still with an ash-pan tried on the *Midi;* the side and back plates were stopped short at an inch or two below the bottom of the fire-box. This ash-pan contracted the air-passage too much, and once full of cinders and ashes, it allowed the lighted pieces to escape freely all round its periphery.

The frequency of fires caused the French Railway Department to appoint a commission to study the means of reconciling the safety of the line with the requirements of working.

But the only interest really affected in the matter was that of the Companies; they paid largely for what they did burn, and at times even for a little more. Indeed the burning of timber and of harvest-produce has been laid

to the engines, not only without proof, but even when the cause of the disaster was very probably some other.

Ash-pan without bottom. — It is very difficult to prevent pieces of fuel dropping through the grate, an effect to which the jolting of the engine, with the long bars out of shape, particularly conduces; but the essential point is less to receive and keep these pieces in, than to prevent their striking against and being projected by the parts of the train, particularly the spokes of the wheels. This was pretty well arrived at by applying to the fire-box ring, two iron sheets side-ways and one behind, going down as near as possible to the surface of the ballast. The pieces are driven forwards and kept on the line by the effect of these sheets, and come to rest without touching any part of train (II, pl. LII, *fig.* 3; Northern of Spain).

This arrangement was admitted in France, by an order of the 1st August 1857, which fixed the minimum distance of the lower edges of the three plates above the rail at 4,72 inches: the engine being loaded and the tyres in their mean state of wear. The hind plate is besides cut out in the middle so as to pass over turntables which have a projecting step-bearing.

Later (10th May 1866) the occurrence of some fires determined the Railway Department « to request the Companies to present their observations on the possibility of modifing the ash-pans employed since the order of 1857, in order to avoid the danger of fire as much as possible."

Many Companies had retained the bottom, at least towards the back; many drivers thought it of advantage to the draught; "the air", said they, "is caught in it like in a wind-sail, which would not be the case if the horizontal plate entirely disappeared."

Experience has not confirmed this influence attributed to the bottom. On the Northern of France, for example, at the request of the drivers themselves the bottom (and even the hind plate) was removed, in the *Crampton* engines as well as in others. It was a question, it is true, of engines with very low fire-boxes, the ash-pans of which were frequently damaged, and it was especially desired to get rid of the trouble which they caused. But it is evident that the drivers would not have delayed to be of with themselves, a measure affecting the activity of the draught. On the *Lyons* Railway, the drivers who believed in the good effects of the bottom, at first protested against the application of simple plates on the sides and behind to the *Crampton* engines. They all alleged that it would be impossible for them to keep up the normal speed of the *expresses* under these conditions. This was taken no notice of, and no driver ever thought of asking for the partial re-establishment of the bottom.

But it is certain that if the partial or total suppression of the bottom was a concession necessary for certain types of engine, the complete ash-pan, with movable front and back, ought to be preferred in every case where it does not restrict the height of the section of the air opening too much, and such is the case nowadays, as the fire-boxes descend so much less. The ash-pan completely closed, but with of course some inevitable leaks, is always useful, especially while the engine is standing. However there are still lines on which the ash-pan is reduced to the three sides, the Eastern of France for example. According to article 76 of General Order No. 5 (locomotive department) of that line:

"At the lower part of the fire-box, an ash-pan formed of three vertical iron-sheets, slightly curved towards the inside prevents the sparks from the fire escaping out on to the line. The regulation distance between the bottom of the ash-pan and the level of the rails is six inches. The hind sheet of the pan is cut out in such a manner as to allow of passing over turn-tables having a projecting step-bearing. The height of the notch is 9,84 inches above the rail."

The use of filled in wheels (II, 310) especially for engines which have an axle behind the fire-box, and for tenders, is a useful complement of the ash-pan. It is little applied, although its efficiency against the throwing up of small burning pieces is well established. Certain engines are not of course adapted for it: those which have the driving axle behind, like the *Crampton* engines, which however as high-speed engines would require this arrangement more than others. But there are parts which are not easily accessible excepting through the intervals of between the spokes; where it is sometimes useful to introduct propelling levers when slight movements are required, the engine being cold. When the line is covered with snow, the ash-pan becomes useless and also impossible if the snow reaches a certain height. In the terms of the Ministerial Order of 30th March 1874, the French Companies may be authorised, at their request, and by abrogation of article 11 of the Order of 1846, to run locomotives without ash-pan, on sections and during periods to be determined.

Spark-arrester in the smoke-box. A grating in the smoke-box, formed of wires 0,20 inch thick, 0,59 inch apart, surrounding the blast pipe and the steam-pipe if inside, without play, attains its end, provided it be well attended to, with coke as well as coal; and at the same time causes no lowering of pressure. Two manometers communicating with the smoke-box, one a little below, and the other a little above the grating, always give identical indications. It cannot thus, contrarily to a rather prevalent opinion, exert the least influence on the draught.

Nowadays, a careful driver by avoiding too reduced a blast opening, especially with very small fuel and runing with bars much out of shape, hardly ever causes a fire. The Companies have at the same time not neglected the supplementary measures; the widening of the ditches, mowing away the dried grass, clearing and cutting away the railway-hedges, especially in forests of a resinous nature, have greatly contributed to the actual fewness of these accidents.

Certain fuels, with the use of which the smoke-box grating would only be efficacious by reducing the blast-opening excessively, and thus interfering with the draught, require modifications in the construction of the chimney itself; as we have already said (8), these modifications will be better considered, with others, at the end of our investigation of the draught.

85. *Shelter for the driver and stoker.* — It is not inappropriate to include the shelter intended to protect the driver and fireman against the weather among safety apparatus. Humanity dictates it in the interests of these men, and certainly the safety of the passengers equally does so. The watchfulness of a driver exposed to the wind, to the cold, to the heat of the sun or blinded by rain or hail, may fail; and the progressive increase of speed has also rendered this measure more and more necessary.

Without contesting its utility in certain cases, the objection has been raised, that even a simple screen supplied with two glazed openings, would be a disadvantage and even dangerous in ordinary weather; that it obstructs the driver's view, and might conceal the signals from him. This is a question of maintenance. The glass must always be kept perfectly clean, as is easy to do; and then the objection fails. The arrangement of the shelters, should also be in accordance with the climate. In France, the simple screen curved backwards is sufficient (II, Pls. XXX and XXXII, Northern of France engines). There is no disadvantage in adding thereto, as on the *Orleans* express engines (II, Pls. XXXV and XXXVII, *fig.* 1), a light roof supported by small pillars, which is useful especially during standing, against the sun and rain.

A simple and solid arrangement applied to most of the engines of the *Méditerranée* system, consists in lengthening the screen backwards and hollowing it out, so that it rests on the continuation of the foot-plate railing.

There is little ground for the side closing of the cab of the *Baden* engine (Pl. XIX). It is however to be found, but with reduced dimensions, in England (Pl. XXII) and in Prussia (Pl. XXIV).

It is natural to do more in extreme climates, one way or the other;

more spacious cabs protect the men either against the cold (Pl. XXV, *Warsaw* to *Terespol* engines) or against heat (Pl. LXVIII, *fig.* 11, East Indies).

But the vast and luxurious cabs applied to the engines of the United States, and which make a sort of boudoir of the driver's platform, carry a good principle to extravagance. Everything therein invites the drivers to sleep, which they cannot always resist, even when they have neither seat nor shelter; and it is a mistake to provoke them thereto by too comfortable arrangements.

86. *Sheathing.* — This envelope is necessary not only for reducing the loss of heat by radiation, but also for the service itself, as the driver and the fireman may want at any moment, while standing, and even during running, to have access to every part of the machinery. The sheathing belongs therefore, in this respect also, to the safety apparatus, seeing that it is indispensable for access to the different parts. It ought to be a bad conductor, light, easy to take down and put up, as repairs of the boiler require it to be completely taken off. Felt packings, kept in place by a layer of wood or thin sheet (0,08 inch), with iron bands, have generally disappeared. They dried beyond measure, and at times took fire at their lower part. It is a layer of air which ordinarily, nowadays, plays the part of isolating substance, and the sheathing proper is almost always of sheet iron or copper, which are alone admissible besides for the lower part of the fire-box, even where wood is maintained for the rest of the boiler. It is supported by small angle irons which keep a layer of air of a suitable thickness (II, Pl. XL, fig. 1, 3, 4).

§ II. — Boiler tests.

87. French legislation (decree of the 25th June 1865 (*), articles 2, 3, 23 and 26) prescribes for all boilers without exception a test made "by hydraulic pressure".

The pressure is measured by a metallic manometer, also graduated by pressure cold.

Even when loaded by a weight, the valve does not suit for the measure of the pressures. If it is not raised, if the water does not spread regularly round its periphery, the regulation pressure is not reached. If these conditions are fulfilled, the fixed pressure is more or less exceeded (73).

(*) This decree of which many dispositions were justly objected to has been just subjected to a careful revisal. Undoubtedly the promulgation of the modified order shall not be long delayed.

"The test consists in submitting the boiler to an effective pressure double that which ought not to be exceeded in service, whenever this pressure is comprised between 7 lbs, 11 and 85 lbs, 34 on the square inch inclusive.

"The extra test load is constanst and equal to 7 lbs, 11 on the square inch, for lower pressures," a case which never occurs with locomotives, "and to 85 lbs, 34 on the square inch for pressures beyond the above limits."

Rules but slightly differing have been adopted by most Continental states.

According to the regulation of the Union of the Northern German railways (*) (art. 9) the effective test pressure is double the effective normal pressure, in service, as long as the latter does not exceed 5 atmospheres. Above that, the excess of the first over the second is constant, and equal to 5 atmospheres.

The technical conventions (**) of 1871 reproduce however (arts. 205 and 206) the old general stipulation of the effective testing pressure equal to once and a half the effective normal pressure, which gives for a boiler working at 9 effective atmospheres, for example, an effective test pressure of 13,5 atmospheres instead of 14 resulting from the preceding rules. In Belgium the effective test pressure is $1\frac{1}{2}$ the effective pressure in service.

88. *Tests by steam at reduced pressure.* — Some builders make, on their own account, before the regulation test cold, a test hot, which permits the leaks at the rivets to be better ascertained and to be remedied before the official test. The boiler filled with water up to the normal level, is heated, but only until the pressure of the "*timbre*", is reached. Under this reduced pressure, leaks are sometimes produced which do not manifest themselves, under the higher pressure of the test cold.

89. *Tests by the expansion of water.* — It has been proposed for the obligatory test, to heat the boiler, filled up entirely with water; a slight elevation of temperature is sufficient then to reach a high pressure, due only to the expansion of the water; but this method is of very nice application. The heat ought to be applied very regularly, and it is difficult to maintain the pressure exactly at the desired point, for the necessary length of time: besides, as the heating surface is in action, the examination of the boiler is difficult and incomplete, all the more that it is not without danger, even at a relatively low temperature. In England the test is optional; in the in-

(*) *Bahn Polizei Reglement für die Eisenbahnen in Norddeutschen Bunde. Statistische Nachrichten von den preussischen Eisenbahnen.* Vol. XVIII, 1870. Appendices.

(**) *Hamburgh meeting.* Technische Vereinbarungen, of 1871.

quiry opened in 1863 on the explosion of a locomotive (*Perseus*) on the Great Western, Mr (now Sir) *D. Gooch* objected to the hydraulic test, done above the running pressure. "None of the great Companies", he said, "accepts it". The position of affairs has greatly changed since then. The test recommended on repeated occasions by the Inspectors of the Board of Trade, has become general, on account of the increasing conviction of its utility. Almost all the railway Companies submit new boilers, and those which have undergone repairs, to the hydraulic press. The London and North-Western only test the first; the Great Northern and the Great Western test neither the ones nor the others. As to prescribed regulations, they are in England the object of extreme repugnance, and they are only applied as a last resource.

Objections against the test cold. — Some engineers think that the test hot proper, that is to say, in steam, and at once and a half the normal pressure would be much more conclusive than pressure cold, in which, three quarters of the time, the regulation limit is reached only for an instant, under the action of the force pump; so that there is hardly time for the leakage to be produced, under the limit of pressure, and that there is much less time still, to ascertain the position and importance of the leaks, and to measure the deformations. The strokes of ram may, on the other hand, develop additional efforts, which it is of consequence to avoid, by working the pumps with short strokes, and especially by giving the tube a small diameter; as to the incomplete filling of the boiler, with the view of leaving therein a cushion of air, this practice exposes the operators to some danger, and should be prohibited. The test cold, lastly, is far from placing the boiler under the real conditions of service, in which so frequently strains come in, due to the differences of expansion, and to the want of freedom of the boiler on the frame. All that is right; but the test cold, even when the pressure is limited to the runing one, must be deemed dangerous; when a boilor in submitted to the test, it is admitted that perhaps it may not resist thereto, and that the operation. may be attended by other effects than simple leaks. Applied often in England, a certain number of years ago, with an excess of pressure of 25 and even 50 per cent and, as would appear, without accident, this mode is rarely applied nowadays. The test hot, even at the working pressure is in reality the suppression of the test, it is the boiler commencing its service in the workshop. The cold process possesses an advantage, one only, but which ought to maintain its preference : it is without danger to those who perform it, even when the pressure exceeds the running pressure by 50 per cent and more.

Objection aganist the test made above the running pressure. — Whatever may be the mode of application, the very principle of the test above the

running pressure, raises one objection : insufficient to enable certain faults to be discovered, the pressure may be capable of increasing them, so that the boiler is less solid and less safe before than after the test. In practical matters, those subtilties which put everything in question must be put aside, and the sacrifice of an almost certain advantage avoided on account of a drawback scarcely probable. Modified as it is nowadays, that is to say to one and a half times, the test is almost always a very sound guarantee, it might almost be said : always, if the test were only the crowning of the complete examination of the boiler, by a competent observer. He who presides at the operation, ought not to be only, so to say, the worker of a pump. If the apparatus is constructed in conformity with the rules sanctioned by practice, and this is the case with locomotives, this examination is simple and easy; if not, the engineer ought to appreciate as a whole, and in its details, the mode of construction of the apparatus, and, while taking great care not to reject novelties, that is to say, progress, to point out to those whom it concerns, faulty arrangements, such as insufficient stays on the flat surfaces, defective joinings; rivets too small in number, the want of consolidation of cylinders working in compression, too small depths of water on the surfaces in contact with the fire, etc.

In order to be quite conclusive in itself, the test ought to include two identical operations, after which the permanent deformations should be measured. If the second verification shows greater deformations than the first, the apparatus ought to be rejected, but it must be admitted that this method would be of very difficult application, in practice.

90. One cannot but regret the passive part to which engineers charged with tests, are reduced, in France, by the decree of 1865. For stationary boilers they have only one thing to do : to proceed to the test; and if the apparatus has stood it, to put on the stamp. In this position, the objection recalled just now must be said to have a certain ground. Perhaps with us, as in England, private initiative, under the form of an association, will take up the part, which the Department has let go. Everything would then be for the best. The great branches of industry of the Parisian group would do a real service by provoking the creation of an inspection, copied from that of England and Alsace; this control of industry by itself, is the quite natural consequence, and the best and sole necessary corrective of the *regime* of liberty (*).

(*) It is now at work in *Lille, Lyons, Paris, Rouen*, etc.

One may feel surprised that it is not yet in action in the United States. In the city of *New-York* for example a regime more severe perhaps than anywhere else, has been put in to force in consequence of several accidents to steam-boilers. It is under the supervision of the municipal police, and it would appear there are frequent convictions for breaking the rules.

§ III. — Explosions.

91. *Mr. Steven's experiments in the United States.* — The causes of the explosions of locomotive boilers have rarely to be discussed nowadays. The more these engines are multiplied, the rarer however, these accidents are.

But if explosions are almost completely avoided, it is not because their causes are perfectly known. For several years, attention has been drawn to the United States, by explosions; which are the more disquieting, as they seem to have taken place under normal and regular conditions of service: the following among others (*).

The 2nd February 1865, a train had just ascended a steep gradient. At the summit, the driver shut the regulator, in order to commence the descent. Some minutes afterwards the fire-box flew in pieces.

According to an eye-witness, the pressure, on arriving on the top of the incline was 129 lbs.; the level of the water very high, the feed pumps working. The author of the report considers that the production of steam continuing, while the expenditure had ceased, the pressure increased in spite of the suspension of the draught, and the action of the feed-water. He adds that the height of the water reducing the volume occupied by the steam tended to make the pressure rise more rapidly, with equality of production.

If the sole fact of the closing of the regulator, at the moment when the regulation pressure is nearly reached and the fire active, were to put the boiler in danger of bursting, the position would be anything but reassuring, seeing that these circumstances very frequently occur in service. But the extreme rarity of explosions proves that such is not the case. When the valves are not sufficient to discharge the steam produced, the driver, who ought to have an eye on the manometer, can and ought always to prevent the pressure increasing, by unscrewing a valve, opening the fire-door wide,

(*) *Journal of the Franklin Institute of Philadelphia*, 1872. *Report of Mr. Isherwood*, p. 401.

feeding, etc. If then, in the case in question, the boiler was really irreproachable in itself, it seems impossible to admit that the driver was so.

The Pennsylvania Railway Company made in 1868, under Mr. *Stevens's* direction, some experiments, from which observers have drawn conclusions that it will be sufficient to reproduce. The question was to verify if the lowering of the level of the water, uncovering the roof, and sudden feeding, can determine an explosion, the safety valves not being extra loaded. The fire being fierce, the level was to be let down until the roof of the box was uncovered, and at a red heat, then the feed was to be put on. Two old locomotive-boilers rejected from service were set apart for these experiments. They communicated by long tubes with a bomb-proof shelter, where the observers were posted.

On account of some misunderstanding, the program does not appear to have been followed from point to point. Whatever that may be, the Commission thought it might conclude from its experiments:

1st. That in order to explain explosions and their effects, it is in no way necessary to bring in, either the lowering of the water, an excessive pressure on account of the suspension of the play of the valves, the instantaneous production of a great quantity of steam, the spheroidal state, or the superheating of the water deprived of air, ceasing at first to produce steam, and producing it all of a sudden in great quantity as soon as the temperature reached the degree which corresponds to its boiling point, less still the formation of explosive mixtures;

2nd. That it is sufficient, in order to determine an explosion, that a gradual increase of the tension take place, up to a limit often little above the normal pressure;

3d. That it is in no way established, that, at the moment of the explosion, there is, as is generally supposed, the sudden formation of a great quantity of steam; *the greater quantity of the water remained, in effect, in the liquid state.*

The two first points escape any precise discussion. In the absence of every particular on the mode of construction, and on the real state of the rejected boilers, which do not appear to have been the object of a rigorous verification, it is hardly possible to assimilate them to apparatus placed under normal conditions. If these boilers were worn, if they had arrived (and nothing shows the contrary), at a state in which the normal pressure might about correspond to the limit of their resistance, it is quite natural that they should have given way, under a pressure which did not much exceed the first. To enunciate the possibility of explosion under similar con-

ditions, is to state a thing so evident, that it has no need to be stated. As to the effects of a untimely feed reaching the surfaces at a red heat, the heat ceded by the metal, can assuredly evaporate but a small quantity of water. But the tenacity of the metal at a red heat is considerably reduced (almost destroyed even, for copper), and the access of cold water determines abrupt contractions therein, and consequently fractures. If the instantaneous disengagement of a great quantity of steam is not the cause of the explosion, it is the consequence thereof, and it may enhance the effects remarkably. The more water, that is to say the more heat or work is stored up in the boiler, the more chance there is for the explosion being disastrous, or at least for the sphere of action of its ravages becoming extended. And seeing that the pressure has only little influence on the total heat stored up, it is not its elevation which renders the explosion more or less serious, but the mass of water contained in the boiler. The pressure does not further increase the chances of explosion, the resistance of the boiler being proportionate to the strains which it undergoes. As to the affirmation that the greater part of the water remained in a liquid state after the explosion, the very vagueness of the terms scarcely permits it to be usefully discussed. As the heat of evaporation is taken from the fluid water, it is evident that the more water there is, the more steam will be formed at the moment of the abrupt fall of pressure, determined by the explosion. But although it is difficult for the most part of the time, to know exactly what the water has become, in a similar case, there is no doubt that the *greater part* remains, in effect, in the liquid state. When a mass M of water passes abruptly from the pressure p, to the atmospheric pressure, and consequently from the temperature $t°$ to 212° F., it sets free an amount of heat $M(q_2 - q_1)$ which is employed, especially, in reducing a mass of water m into steam, such that: $M(q_2 - q_1) = m(\lambda - q_1)$, q_1 and q_2 being the *liquid heat* at 212° F. and at $t°$, and λ the total heat necessary for transforming the unit of weight of water at 32° F. into steam at 212° F. For $p = 10$ atmospheres, we have: $q_2 = 328°,90$; $q_1 = 180°,9$; $\lambda - q_1 = 1090°,9 - 0,695\,t - 0,00002\,t^2 - 0,0000003\,t^3$, and for $t = 180°$, $\lambda - q_1 = 859°,3$.

whence $$\frac{m}{M} = \frac{q_2 - q_1}{\lambda - q_1} = \frac{1}{6,5}.$$

The experiments of the American commission leave altogether the question exactly at the point at which they took it up. No one contests that what are called "*ordinary causes*" are sufficient to explain most explosions; but to reject absolutely what are called "*mysterious causes*" more

or less complex, it would have to be proved that the first are sufficient in all cases. This proof has still to be given (*).

92. *Law of increase of the tension in a closed boiler.* — It is easy to determine approximately, the law according to which the temperature increases, and consequently the elastic force in a boiler, when the fire is kept up with a given and constant activity; the expenditure being suspended by the closing of the regulator and by fastening down the safety valves, or at any rate, not reaching the load on them. M lbs. being the weight of water contained in the boiler, a weight against which that of the steam may be neglected, t_1 the internal temperature at the origin, t_2 this temperature at the end of the time τ, c the specific heat of the water, or 1,0224 in mean, and Q_0 the quantity of heat introduced in the unit of time, we have:

$$Q_0\tau = Mc(t_2 - t_1) \quad \text{or} \quad t_2 - t_1 = \frac{Q_0\tau}{Mc};$$

the elevation of temperature $\frac{Q_0\tau}{Mc}$ is thus proportional to the time τ; per unit of time, it is proportional to Q_0, and consequently to the heating surface, and in the inverse ratio of M. It is thus particularly great for locomotive boilers; the principal character of which is the largeness of the ratio of the heating surface, and consequently of Q_0, to the mass of water M. Hence, the sensibility of these apparatus, a sensibility that cannot be too much impressed on drivers. This is what is done by the instructions already cited (76) of the Méditerranee locomotive department:

"The explosion of engine 1.522, at *Moulins*, is a sad example of the consequences of the fatal habit of fastening down the valves. They were fastened down; the strings were found broken, but still attached to the balances. *A stoppage of a few minutes at Moulins and three minutes slow running were sufficient to bring up the tension high enough to produce an explosion.*"

Instead of laying down directly, as we have just done, the approximate expression above, M. *Zeuner* (**) deduces it from the exact value, which we shall confine ourselves to repeating.

q_1 and q_2 being always the *heats of the liquid* and ρ_1 and ρ_2 the *internal latent heats* of the steam at the temperatures t_1, t_2; x_1 the weight of steam in the unit of weight of the mixture of steam and water, at the initial tempera-

(*) See : *Annales des travaux publics de Belgique.* Vol. XXV.

(**) *Théorie mécanique de la chaleur.* 2me édition, page 315.

ture t_1; u_1, u_2 the relative volumes of the steam at the temperatures t_1, t_2; or more exactly, those volumes diminished by that of the generating water, at the same temperatures; Q the quantity of heat introduced, to carry the weight M lbs. in closed vessel, from t_1 to t_2, we have:

$$Q = M\left[q_2 - q_1 + x_1 u_1\left(\frac{p_2}{u_2} - \frac{p_1}{u_1}\right)\right].$$

as besides: $$Q = Q_0\tau,$$

we have $$\tau = \frac{Q}{Q_0} = \frac{M}{Q_0}\left[q_2 - q_1 + x_1 u_1\left(\frac{p_2}{u_2} - \frac{p_1}{u_1}\right)\right];$$

x_1 being a very small fraction, the terms in it can be neglected, whence $\tau = \frac{M}{Q_0}(q_2 - q_1)$, and as c is the mean specific heat of water, we have nearly: $q_1 = ct_1$, $q_2 = ct_2$.

$$\tau = \frac{Mc}{Q_0}(t_2 - t_1).$$

Mr. Fairbairn's experiments. — On the occasion of the explosion of a locomotive at *Manchester*, an explosion attended with very serious consequences, a dispute took place, in 1853, between the Board of Trade inspector and Mr. *Fairbairn*. The first denounced the construction of the boiler, and particularly the mode of staying the box and the inside shell; the second maintained that the boiler was irreproachable, and that the explosion which took place while the engine was standing, was caused by the fastening down of the valves, a fact which besides was ascertained; that twenty five minutes had elapsed between the fastening down of the valves, and the explosion, and that this time was sufficient for the tension, which was at 5,2 atmos., to reach 21 atmos. at least.

An engine of the same type, placed by the London and North Western, at the disposal of the eminent engineer, was lighted and left to itself, the fire being supplied in the usual way, and the progress of the pressures was observed:

Time, in minutes.	0	4	6	8	10	12	13	16	18	20	22
Absolute pressure in atmospheres....	1,82	2,56	3,02	3,5	4,09	4,69	5,04	6,3	7,1	8,1	8,8
Temperature in degrees Farenheit...	243	264	273	283	293	302	306	317	330	340	347

The limit of pressure, close to 9 atmospheres, was already high for the time. Twenty two minutes had sufficed to pass from 1,8 atm. to 8,8 atm.

Mr. *Fairbairn* concluded therefrom, that the pressure was perfectly well able, the fire being in the same state, to rise in the boiler, in which the accident took place, from 5,2 atm. its uncontested initial value, to 21 atms. and even beyond, in 25 minutes.

This conclusion is legitimate. The constancy of the increase of temperature per unit of time comes out of the expression

$$\frac{t_2 - t_1}{\tau} = \frac{Q_0}{Mc},$$

and it is confirmed by Mr. *Fairbairn's* ten observations above; they give in effect, for the mean value of the increase of temperature per minute:

2°,25; 4°,41; 4°,77; 5°,04; 4°,59; 4°,39; 5°,37; 3°,92; 4°,95; and 3°,6; or on the average 4°,61.

The initial pressure being 5,2 atmospheres, and consequently the temperature, 305°,6, the latter would thus rise, everything else equal, at the end of 25′, to: $305°,6 + 4°,61 \times 25 = 421°$, a value which corresponds in effect to 21 atmospheres.

For $t_2 - t_1 = 4°,61$; $\tau = 1$; $c = 1,0224$, the formula gives:

$$\frac{M}{Q} = 0,68.$$

The values of M and Q not being given, we cannot verify if they satisfy that equation.

In an experiment made in the United States, on a marine boiler, the valves being fastened down, 13 minutes only were required to raise the pressure, without hurrying the fire, from 2 to 4 atmospheres, which determined a formidable explosion (*).

§ IV. — Feed.

93. *Feeding apparatus.* — The *Giffard* injector has, almost everywhere, replaced pumps in locomotives; for which it is the more suitable, as it allows feeding to be done while standing, without having recourse either to the inconvenient and insufficient expedient of buckets (*galets d'alimentation*), or to the little donkey-engine employed in Germany. In spite of the absence of all mechanism in movement, the injector at times causes breaksdown, especially on account of obstructions. But accidents are much more rare, even with one single injector, than with the two pumps. A single

(*) *Audenet.* Étude sur les chaudières marines, pamphlet in-8, 1874, page 48.

Giffard is thus sufficient; and when two are applied, they are often of different powers, the one for small, the other for heavy feeds.

The principle objection which has delayed, especially in Germany, the application of this beautiful invention, is the limit which it imposes on the temperature of the feed-water; the condensation of the steam being badly effected when the temperature of the water exceeds about 104°, especially with steam at the high pressure, and consequently at the high temperature, in use nowadays. According to Mr. *Robinson* the temperature of the water ought not to exceed respectively 150°, 138°, 129°, 124°, and 111°, for absolute pressures of 2,2; 2,9; 3,5; 4,1 and 7,3 atmospheres.

The injector is little employed in the navy; where it is objected to it because it takes over much air into the boiler with the water.

It was a serious matter to give up the habit got into by the drivers of certain of the lines of the North of Germany, and very justifiable, in winter, on account af the severity of the climate, of running with the water in the tender very hot, and carried even to 212°, by the partial condensation of the exhaust steam. But at last it was recognised that this cannot be put in the balance against the advantages presented by the injector.

The injector introduces hot water into the boiler; this water is heated, it is true, by heat taken from the boiler, and not by heat which would otherwise be lost. But although reduced, the advantage is however still real; the local cooling and contraction of the sides of the boiler, close to the point where the water comes in are less than if the water were cold. The gravity of the fact depends, moreover, on the mode of feeding, wether intermittent, or continuous. In the second case it is slight.

The following observations, made on the Southern of Austria line, make known the elevation of the temperature of the feed water, in consequence of its mixture with the steam in the apparatus:

TYPE OF INJECTOR.	ABSOLUTE pressures in the boiler.	TEMPERATURE OF THE WATER. drawn.	TEMPERATURE OF THE WATER. forced.	RISE of temperature.
	atmospheres.	degrees F.	degrees F.	degrees F.
	8,4	82,4	136,4	86,0
	8,4	105,8	168,8	95,0
Schau, No 9 1/2	9,0	109,4	183,2	105,8
	8,4	105,8	168,8	95,0
	8,0	109,4	167,0	89,6
	8,0	118,4	183,2	96,8
	9,0	104,0	168,8	96,8
Ditto, No 8	8,0	109,4	167,0	89,6
	8,0	118,4	183,2	96,8
Friedmann, No 7	9,0	86,0	161,6	107,6

Pumps have not disappeared as completely as might be believed. On the *Orléans* system, for example, each engine receives an injector and a pump; the first being specially intended for feeding while standing, and the second for feeding during running, for which the injector is looked upon as less suitable, when the feeding has to be nearly continuous, according to the rule adopted on those lines.

It is however also a question of profit. On the descent of gradients of too slight an inclination to require the application of counter-steam, the pumps allowed the feeding to be done without expense; they act moreover as a break, so that gravity produces two useful effects at the same time, by the intermedium of the pumps.

The eight wheels coupled engine, constructed at the *Creusot*, specially for the service of the *Capvern* incline, worked up to the present time by six-wheeled engines (II, 406 to 416), have one injector, and one pump, worked by an eccentric keyed on to the leading axle.

Counter-steam acting on the descent of this incline of one in 31, it was judged prudent to provide against the refusal of the injector to work, on account of the introduction of air into the boiler. The pump is thus warranted, in this case, by the use of counter-steam, while it is so, in the preceding case, by the contrary fact.

Sometimes a pump is kept, in order to allow feeding with hot water, when desired; example : engine with working-tender of the Central Belgian (II, 402, and Pl. LXX, *figs.* 2 and 3); the pump is driven by a donkey engine.

We shall not describe the injector, which, having become the classical feed-apparatus for all steam-boilers, is no longer special to the locomotive. Let us point out only the arrangement adopted by Mr. *J. Webb*.. The injector is vertical, is bolted on to the back of the fire-box, and forms the direct

continuation of the tube communicating from the tender to the boiler. It thus serves, at will, either for feeding the second, or for heating the water in the first.

94. *Comparative experiments on the injector and pump.* In 1860, M. Vuillemin made some experiments in the Épernay workshops, on the gross evaporation, per lb. of the same fuel, of the same boiler, fed either by ordinary pumps, or by the injector.

A *Crampton* engine (No 86) was placed on a line, with its driving wheels raised, so that it remained stationary.

The experiment consisted : 1st, in making the machinery act by expending the steam produced; first, feeding with the pumps; 2nd. stopping their action, and feeding with the injector.

2nd. To measure exactly, in each case, the weight of the fuel burnt, and of the water evaporated.

The quantity of steam expended by the action of the machinery being constant, the difference between the consumptions, could only be imputed to the feeding apparatus.

The temperature of the water was in all cases 10°,7 to 12°,6.

DATES.	INDICATIONS of the experiments.	LENGTH of time running.	NUMBERS of revolutions of the driving wheels.	PRESSURE.	COKE BURNT.		QUANTITY of water evaporated.		OBSERVATIONS.
					Including lighting.	The lighting deducted.	During the experiment.	Per lb. of coke the lighting deducted.	
1860		hours.		atm.	tons.	tons.	lbs.	lbs.	
5 March.	Engine running with the two pumps filled one only driving water in.	11 00′	76.450 = 116 per 1′.	5,25	1,230	1,131	22,101	7,18	Mean : 7,355 lbs.
9 March.	Ditto.	11 4′	86.850 = 131 per 1′.	5,60	1,180	1,082	22,184	7,53	
7 March.	Engine running with *Giffard's* injector, the two pumps taken down.	11 9′	100.828 = 151 per 1′.	5,50	1,180	1,082	25,276	8,58	Mean : 8,335 lbs
13 March	Ditto	12 15′	107.138 = 148 per 1′.	5,75	1,180	1,082	23,835	8,09	

It results from these experiments :

1st.	That 1 lb. coke produced, with the *Giffard*....	8 lbs,335	of steam.
2nd.	Do do with pumps.....	7 ,355	do
	Difference in favour of *Giffard's* injector.....	0 lbs,980	do

or, about 13,3 per cent more than with the pumps.

Whatever care may have been exercised in making these observations, their results should only be accepted with reserve, the more so as this mode of estimation by difference is in itself subject to much greater possibility of error than a direct measurement. Theory points out besides, that, as feed-apparatus, the injector is *perfect*, the *vis viva* lost by the abrupt changes of velocity, being transformed into heat, which returns to the boiler. Even if it did not possess all the superiority of useful effect attributed to it by the preceding figures, the advantages which it does possess beyond contestation, in all other respects, would amply suffice to insure it the preference.

Let us cite also the following observations on the quantity of water furnished, under different pressures, by an injector of 0.30 inch (small diameter of the divergent tube).

	FEED WATER HEATED TO 59° (F) Duration of each experiment 3 minutes.						
Initial pressure.....	9.0 ats.	8.5 ats.	7.4 ats.	7.0 ats.	6.1 ats.	5.4 ats.	5.3 ats.
Final do.....	7.8 do.	uncertain.	7.7 do.	6.0 do.	5.3 do.	4.9 do.	4.8 do.
Water injected per sec.....	23.9 gals.	do.	23.3 gals.	20.9 gals.	20.2 gals.	19.3 gals.	17.9 gals.

These experiment were made on the engine standing, only consuming the steam necessary to supply the injector.

95. *Details as to pumps.* — Pumps are now so generally abandoned that it will be sufficient to recall the essential points referring to their application:

1st. The plunger, driven sometimes by a special eccentric (II, Pl. LXIV, *fig.* 1) is more ordinarily worked by an arrangement of the machinery : sometimes by the cross head of the piston itself, sometimes by one of the eccentrics of the valve motion, and naturally by that of the reversing gear, as that works less than the other; a difference insignificant enough with link-motions. In order to increase the length of the rod, it is jointed on to the very bottom of the plunger, which is hollow, and the diameter of which is large enough, on account of the smallness of the stroke which is equal to that of the valve, to allow the rod free play.

2nd. There are in general two suction valves. These valves, and their seats do not differ from the delivery-valve except in position, the two first being between the tender and the body of the pump, and the third between the body of the pump and the boiler.

3rd. It is desirable that the insertion of the delivery-pipe into the boiler should be provided with a stop-cock with the key always in its place, and kept on the square by a pressure screw *v* (Pl. IV, *fig.* 20 *cc*), in order that the driver may be able to close it immediately in case of the valves going out of order.

4th. These valves are not clacks, but balls, in bronze, and hollow, in order to reduce their mass, and consequently the intensity of their shocks. The hollow interior must be perfectly spherical, and well centred; the centre of gravity coinciding with the centre of figure, the ball comes down equally in all positions, on to its seat. Otherwise, il would come down chiefly in its position of stable equilibrium, would not wear uniformly, would lose the spherical shape, and the accidental deviations in the the position of its equilibrium, would prevent its closing the opening in the valve seat. Some builders have kept, and even returned to solid balls, alleging the difficulty of obtaining a uniform thickness. There is not much reason in this; but the duty performed by pumps is now too secondary a consideration for us to dwell upon.

5th. The valve-boxes are ordinarily closed at the top by a cover with a strap bolted over, carrying a pressure screw butting against the top of the house which contains and guides the ball. In case of an obstacle preventing ball from coming down on its seat, a few moments are sufficient for the driver to take off the cover, remove the obstacle, and replace the ball.

96. *Point of insertion of the feed-tube into the boiler.* — The point of arrival of the water into the boiler is not indifferent. This water, being relatively cold, should be brought in where gases are the least hot, and this leads the point of insertion of the feed pipe to be placed towards the front of the cylindrical barrel, a measure justified by another consideration, vizt that of the deposits. Where the water arrives, there the deposits form in greater quantity, and the more so the greater the difference between the temperatures. Placed towards the front of the cylindrical barrel, near the washing-out plug in the tube plate, this deposit is easy of access and of removal. The point in question ought besides to be sufficiently distant from the fire-box, and particularly from the tube plate, to which the access of the cold water would be a further cause of abrupt contractions. It is

desirable besides, as has been already said (38), to avoid having this point near the intake of the steam, as that would have the effect of producing a local fall of pressure. Lastly, also, the water ought to arrive at a small distance below the mean level, in order to avoid the obstruction of the opening by deposits, and bring *convection* into play; that is to say, the play of the difference of the densities which determines the formation of currents, and thus supplies an inspection of the defect of conductibility natural to water. The plates of Vol. II, will show that these relations are generally observed, except where it has not been scrupled to place the feed-cock immediately below the steam dome (II, Pl. XXXV ; XXXVIII, LIII, etc.).

Sometime even the delivery-tube is let into the fire-box, and towards the bottom, which is in opposition to the preceding principles, unless however as regards the formation of deposits, which are then much greater, in a region close to the blowoff cocks, and are easily cleaned, especially if the grate is sufficiently raised (36). The disadvantage consists chiefly in the exaggeration of the effects of abrupt changes of temperature ; but this objection, which is serious in the case of pumps and cold water, is much less so with *Giffard's* injector.

§ V. — Water.

97. *Nature of the water.* — With the powerful engines now in use, and under actual circumstances, the total expense per train-mile has come down to the old figure of about 2 s. 6 d., of which on the *Mediterranean* lines for example, 1 s. 3 d. is for haulage, and maintenance of the rolling-stock. In this figure, the haulage proper enters for 7 3,4 d., the expense for water for 0 s. 0,0256 d. (39), a figure ordinarily less still, while the maintenance of the engines enters for 0 s. 3,4 d. (*) a figure which, to be complete, should include the extinction of the capital.

Notwithstanding the considerable works made to insure sufficient supplies for the water service, and of good quality, this item is, we see, relatively insignificant, while the cost of the maintenance of the engines, already so

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(*) These two figures are those of the working of 1873 *s*; they have increased during the last three years, on account of the increase of the mean power of the engines, and also, in 1872, from the excessive, though temporary rise in the price of coal, etc. On the Southern lines, 1873's working, the expense of haulage and of the maintenance of the rolling stock per mile is : 1s. 3,0 d, of which total 0,0245 d for wate supply, and 0,25 d, for the maintenance and repairs of engines and tenders.

On the *Orléans* lines 1873's working, these figures go down respectively to 1s. 0,56d, 0s. 0,01 d, and 0s. 0,163 d. There is no occasion for entering here, on the subject of their relative lowness into a discussion several elements of which are besides wanting.

high, would be much higher still if the water were of bad quality. This is only too fully proved by the very onerous maintenance, on the lengths where, at present, bad water has to be put up with; the expense of maintaining the boilers, is, on the contrary, almost nothing, when pure water is made use of, such as that of the Swedish lakes, for example.

At a meeting in *Baltimore*, the *locomotive committee* of the Society of the Mechanical Engineers of the United States, estimated the increase of the annual expense of maintenance due to the impurity of the water at £ 150 per engine. The committee recommend storing up rain water, for feeding purposes; and estimates that the expense of establishment would be very soon covered by the economy of maintenance.

The bad nature of the water arises sometimes from its acidity, and much more frequently from the considerable proportion of earthy salts which it holds in solution. These salts are chiefly the sulphate of lime and the bicarbonate of lime, which separate as the temperature rises in the boiler, the first because it becomes less soluble, and the second, because the carbonic acid which kept it in solution is set free. The carbonate, being lighter, remains longer in suspension, and has less tendency to solidify; but the presence of the sulphate, which mixes with it, accelerates the formation and hardening of the deposits.

Deposits without chemical action on the metals of the boiler would be, in general, almost inoffensive, if like those which most troubled waters form, they did not adhere to the surfaces. But they adhere to them with a force which increases with time, as well as with the thickness of the crust, which soon withstands the simple means of washing out. On account of this interposition of substances which are very bad conductors of heat, the evaporation slackens, at the same time that the consumption of fuel increases, and often in enormous proportions, and as much in the case of copper as of iron, the influence of the conductibility proper of the metal, disappearing against that of the isolating deposit, (unless, as would result from the observation cited in No. 45, the nature of the metal can exercise a marked influence on the thickness of the deposit); the temperature of the metal in contact with the fire on the one side, and not cooled on the other by the immediate contact of the water, rises greatly, and its resistance diminishes in consequence; the differences of expansion thus enhanced, strain the plates, especially at the joints; some persons see even a possible cause of explosion in the accidental cracks of the crust, bringing the water into contact with the superheated metal : an opinion doubtless with little foundation, as to the immediate cause ordinarily al-

leged, that is to say, the instantaneous disengagement of a great quantity of steam; but the contact in question produces an abrupt local contraction, and fractures in the metal, which is very much weakened by its high temperature.

On account of the difficulty of cleaning locomotive boilers, and from the multitude of their joints, the use of water yielding deposits is attended with more serious consequences, than in the case of ordinary boilers. It has often been a matter of regret in industrial undertakings, that the tubular type should have been adopted without having previously made sure of the quality of the feed-water.

It is not only by their direct action that deposits are so injurious. Thus, one of those causes which strain the tube-plates the most, is the extraction of the tubes (27), and this operation is the more frequent, and difficult, in proportion to the deposits made by the water. A deposit of tartar contributes also much to the twisting of the tube plates, on account of the high temperature to which they are then subjected.

Tubes which, with good water and an ordinary annual distance run, last from three to five years, have to be changed at the end of two years, one year, and even less when the water is bad.

Soapy deposits, not adherent. — The solid and adherent deposits are not always, as is often believed, the only ones, nor even the most dangerous. The carbonate of lime, particularly, when it is mixed with fatty matters, forms a sort of insoluble soap, which remains a long time in suspension, and concentrates itself towards the lower parts of the boiler where it forms with the water a viscous mixture, not adherent, but which opposes great resistance to convection, and to the disengagement of the bubbles of steam. The latter, accumulating on the metallic surfaces, places them under the conditions most conducive to violent super-heating. The deposits of this nature, which dry, present themselves in the form of an impalpable powder, act thus indirectly checking the layer of steam, which in this way plays the part of isolating deposit.

The fact which in this case takes place on a large scale, is constantly observed on a small scale, and in the open air, in that most widely spread of all branches of industry: what do I say! in the most widely spread of all arts, the culinary art, in which we so often see vessels heated on the open fire, get burnt because their pasty contents oppose the disengagement of the steam from the water and keep it applied against the side, which burns; the steam finishes by overcoming the obstacle, the contents come into contact with the side, and are burnt in their turn; an accident

easily prevented, by constant stirring in order to facilitate the disengagement of the steam, the transmission of the heat, and thus prevent the overheating of the side.

The habitual presence, in water coming from the condensation of the exhaust steam, of a certain proportion of grease carried over, is one of the motives which prevented this mode of heating the feed-water becoming general, before another reason still more powerful caused it to be given up altogether (93).

98. *Periodical washing out of boilers.* — Extraction properly so called, the object of which is to prevent the water reaching the point of saturation, and avoid the formation of deposits, cannot be applied to precipitates already formed. The carbonate of lime, especially, is maintained in suspension during a period more or less great, and towards the surface, by the agitation of the water, and this suggested the idea of the *dejectors*, which up to the present time have not succeeded; so that the normal mode, consists essentially in letting the boiler cool down, the deposits to form by rest, and to remove them by washing out with water under pressure. These washings ought to recur at shorter intervals, the more abundant the deposits, and especially the more tendency they have to harden rapidly. When the deposits, at first non-adhering, remain too long in the boilers, they become attached thereto, especially at those parts exposed to the fire, and require a much more energetic action of the tools, to which the least possible scope ought to be allowed.

The boilers ought to be washed out, first, after each period of service, whatever may be the distance run, because cooling down favours the settling of the deposits; second, after a fixed distance run, which varies in the inverse ratio of the quantity of fuel burnt, or water consumed per mile, and of the proportion of deposits yielded by the water.

Example: Mediterranean lines. First section of traction :

1st. Express engines consume 26,6 lbs per mile, and evaporate per lb. 8 lbs. of water, giving by evaporation to dryness 0.00024 of deposits (Seine water, see the table which follows). Good results are obtained by washing out after a distance of 1,243 miles run, that is to say, when the weight of the deposits reaches :

$$26{,}6 \text{ lbs.} \times 8 \times 0{,}00024 \times 1243 = 63{,}49 \text{ lbs};$$

2nd. Ordinary train engines :

Mean consumption of coal per mile 30,2 lbs ; water evaporated 149,9 lbs.

Washing out at the end of 1,056 miles ; weight of the deposits

$$149{,}9 \times 0{,}00024 \times 1.056 = 61{,}07 \text{ lbs.}$$

3rd. Goods engines :

Mean consumption of coal per mile 53,1 lbs. per mile; water evaporated 264,55 lbs.

Washing out at the end of 621 miles ; weight of the deposits,

$$264{,}5 \times 0{,}00024 \times 621 = 63{,}49 \text{ lbs.}$$

If the washing out amounts in the three cases to the same quantity of deposit, it is because the heating surfaces differ little, and that the inferiority, in this respect, of high speed engines is compensated by a greater production per unit (20). For engines with eight wheels coupled, for example, the deposits being distributed over a much greater surface, might reach a more considerable total weight, but not in the ratio of the surfaces, the distribution of the deposits being far from uniform, and the necessity of washing out resulting from the abundance of deposits at the points of accumulation, and not from their mean thickness.

To the special services of the great lines of railway are attached chemical laboratories, which render great service, and on which naturally devolves the testing of the different waters, as well as that of the different sorts of fuel. But for a summary appreciation a test by the hydrometer of MM. *Boutron* and *Boudet*, is often considered sufficient. This method of testing, is founded on a fact observed long ago by Dr. *Clarke*. If, while agitating, ordinary soap be added to water, the froth which forms immediately when the water is pure, does not show itself, if the water contains earthy salts in solution, until after their complete precipitation. In making use of a solution with a graduated amount of soap in it, the quantity necessary to determine the formation of the froth is proportional to the quantity of salts precipitated, and the degree of chemical impurity of the water is measured by the number of the degrees of the hydrotimeter. One degree corresponds very nearly to $\frac{1}{100.000}$ of solid matter in solution.

The *Mediterranean* locomotive department has determined, by experiment, the residue given by the evaporation to dryness of almost all the different waters it makes use of. The following table gives some examples of this :

STATIONS.	LINES.	SOURCES OF THE WATER.	PROPORTION contained in 1000 parts of water.
Solliés-Pont	Line from Marseilles to Nice	Well	0,935
Alais	Line from St-Germain-des-Fossés to Nimes	Spring	0,784
Les Arcs	Marseilles to Nice	do.	0,766
Saint-Cyr	do	Tunnel springs	0,700
Pas-des-Lanciers	Lyons to Marseilles	Water from la Nerthe	0,625
Villeneuve-Saint-Georges	Paris to Melun	do	0,614
Bonny	Paris-Lyons by le Bourbonnais	do	0,512
Clermont-Ferrand	Saint-Germain-des-Fossés to Nimes	The bridge of Noud	0,487
Chambéry	Valence to Chambéry	Spring	0,480
Sens	Paris-Lyons	Yonne	0,478
Rive-de-Gier	Saint-Étienne to Lyons	Gier	0,451
Besançon	Dijon to Belfort	Doubs	0,425
Le Puy	Saint-Étienne to Langeac	Spring	0,385
Roquefavour	Rognac to Aix	La Durance Canal	0,288
La Mouche (Lyon)	Lyons to Marseilles and Geneva	Rhône	0,263
Paris		Seine	0,240
Corbeil	Paris to Montargis	do	0,230
Rives	Lyons to Grenoble	La Fure	0,176
Geneva	Mâcon to Geneva	Lake of Geneva	0,167
Annecy	Aix to Annecy	Spring	0,145
Tarare	Paris-Lyons by le Bourbonnais	Rain water	0,106
Etang	Étang to Chagny	L'Arroux	0,100
Breard	Nevers to Chagny	Loire	0,057
Montceau-les-Mines	Chagny to Montceaux	Springs and drainage	0,047
Alais	Saint-Germain-des-Fossés to Nimes	Gardon	0,045
Cercy-la-Tour	Nevers to Chagny	L'Alène	0,044

These figures serve for base, as we have just seen, for fixing the periods of washing out.

99. *Mode of washing out.* — For washing out as for filling, the introduction of cold water into a boiler still hot, ought to be rigorously prohibited. Nothing more certain, in effect, to produce leaks, than abrupt variations of temperature. The boiler ought at the same time never to be emptied, before it has cooled down; for, in the absence of water the heat transmitted by the plates greatly hardens the deposits.

There are sometimes applied to surfaces covered with adherent tartar disastrous expedients, from which however locomotives generally escape, thanks to the good organisation of the service. These expedients are founded on the action of an abrupt difference between the temperature of the metal sides, and of the deposit which adheres thereto : the one consists in emptying the boiler under the action of the steam, and immediately introducing cold water; the tartar, contracting before the metal, breaks and is easily detached. The second, less violent, is the reverse: the boiler, cooled, is put into communication with another boiler, from which it receives steam at as great a pressure as possible. The tartar, immediately

attacked by the steam, expands more than the metal, and the effect is the same.

It is unnecessary to say that both of these methods ought to be rigorously interdicted. Every abrupt change is so much the more injurious to the boiler, that all its points are never reached at one time. The boiler ought to be cold, and receive only cold water. It ought to be cleaned out, if possible, frequently enough for the tartar not to have time to harden. If besides, the water can be allowed to continue to act during a certain time, so much the better; as the sulphate of lime partly redissolves. All the cocks, plugs, and self-closing orifices, being open, water is successively injected, by means of copper nozzles with straight or curved mouth-pieces, under pressure through all the openings, and in every direction. At the same time by means of flexible iron rods, terminated by crooks, every part as much as possible is reached, especially of the fire-box, in order to detach the encrusted matters, which the water drives out in pieces. The operation is continued as long as any particles are brought over. The washing out completed, the driver shuts all the openings, and fills the boiler.

One of the advantages of the methodical classification of the tubes (25) is, that they can nearly all be replaced at the same time; the whole of the cylindrical barrel is thus directly accessible to chip off, if required, the tartar by the chisel, which should, like the caulking tool, to be handled with the greatest care, and confided only to experienced hands. But when the complete replacing of the set of tubes cannot be waited for, there should be no hesitation, at need, in taking out temporarily, some of the lower tubes, in order to allow the workmen to have access to the bottom of the cylindrical barrel, either by the man-hole, or by the other openings.

It is often necessary, also, to clear out the space above the fire-box, by taking down a part of the ties by which the roof stays are suspended, in order that the tools may get at the vertical sides of the inside box and the outside shell, an operation which is besides often very difficult, for fire-boxes widened out at the top.

100. *Cleaning the tubes inside.* — That the surfaces in contact with the flame should be perfectly clean, is also an essential condition of the transmission of the heat. It is particularly soot that is deposited on them. The inside cleaning of the tubes is easy; in Alsace, they use an injection of steam for stationary tubular boilers. The same means is sometimes applied to locomotives, either concurrently with the brush and rod, or in prefer-

ence to the latter. *Fig.* 21, pl. IV, represents a small apparatus employed in England. In the ferrules of the smoke-box, a nozzle is inserted *a*, receiving by a flexible tube *t*, steam brought by the little conduit θ, and the admission of which is regulated by the valve *s* and the lever *l*.

§ VI. — Means of preventing the formation of solid and adherent deposits.

Water not subject to form adherent deposits being the exception, other water has of course to be employed in a multitude of cases, by accepting its defects if these are tolerable, and by endeavouring to correct them if they are excessive.

There are in principle two classes of processes. In effect: 1st, the more or less complete precipitation of the earthy salts may be determined, either before the introduction of the water into the boiler, or, after its introduction, but before its mixture with the water which it contains; 2nd, the water may be introduced such as it is, accepting consequently the deposits, but by endeavouring to localise them at points where their extraction is easy, or indeed in preventing them, by the addition of appropriate substances, from adhering to the metal sides.

101. *First class. Previous precipitation. — a. by heat.* The heating of the water in the tender might carry out this precipitation, but incompletely, the sulphate of lime, the carbonate retained in solution, after the expulsion of the carbonic acid in excess, only becoming quite insoluble at 302° F. We have already seen (93) that feeding by *Giffard's* injector has generally led to the giving up of a considerable amount of heating of the tender-water, which was brought up nearly to boiling point by the partial condensation of the exhaust steam.

What cannot be done in the tender, has been sought to be done, and in appearance much more efficaciously, in a special compartment of the boiler itself, a compartment occupied by the steam, and where the water, admitted in the form of spray, and brought up to a high temperature, comes into contact with horizontal metallic plates alternating, upon which it spreads in thin films. It was considered that the water being brought instantaneously up to the temperature of the boiler, the salts would be precipitated on the plates, while the water would pass off into the boiler.

In *Schau's* apparatus (Pl. III, *figs.* 9 and 10), the carrying out of this very

specious idea, attains the object very incompletely. The water arrives by the tube T in the compartment D, which surmounts the boiler, spreads out in a thin film through the annular opening *nn*, passes from one plate (*p*,*p*,*p*) to the other, by the contrary holes *o*, *o*, and enters the boiler through a pipe passing among the tubes of the boiler 0. The plates keyed on to the three rods *t*, *t*, *t*, are easy to remove, and to replace. Unfortunately, the deposits have not time to be formed, between the instant at which the water penetrates into the dome, and that in which it becomes mixed with the mass. The Austrian Engineer's Journal gave, it is true, the example of an engine on the line from *Vienna* to *Neu-Szöny*, which, after a distance run of 54.560 miles had deposited on the plates 40 lbs. of deposits, while the boiler not only remained intact, but had got rid of a crust of from 0,27 to 0,28 inch which had covered its sides at the commencement of the experiment. This was most excellent, but it was a peculiar case, and even appears, to be unique. An application made on a dozen engines of the *Staats-Bahn* proved that the deposit formed on the apparatus, was, on the average, 30,6 per cent of the solid matters contained in the water; but the deviations were very great. Thus, while for two engines this proportion amounted to 72,55 and 76,86 per cent, it was for two others 51,5 and 42,1 per cent, and went down for the remaining eight, from 29,5 to 10,2 per cent. These differences were in proportion to the nature of the earthy salts. In the apparatus in question, the carbonates deposited first, the sulphates with more difficulty and incompletely. This process seems thus to be suitable, not for water with a great deal of selenite, but for water very much loaded with calcareous matter (which is however the most frequent case, and especially with *Giffard's* injector, the water introduced, already hot, necessarily attaining the temperature at which the deposits form, more rapidly; but these advantages have not been borne out. What is certain is, that the company having intended to apply the apparatus on a large scale, gave up the idea upon fuller information.

The Eastern of Prussia found this apparatus much inferior, as preventive means against incrustation, to M. *Kirchweger's* method of condensation, which only however determines the deposits in the tender, at the temperature of 212° at the most, but in which at least the action has time to be produced.

On the Eastern of France, *Schau's* apparatus applied to engine 0,165 on the line from *Nancy* to *Forbach* was given up at the end of 15 months running. For a long time previously no one had paid any attention to it, so fully established was the opinion of its inefficiency. After running 11.810 miles

the lower plate only had a little tartar on it, and the boiler had still its usual amount of deposits (*).

Dejectors. An attempt has been made to effect the separation of the deposits by producing, in the boiler, a current which carries them off immediately they are formed, and abandons them, in losing its velocity, in a receptacle arranged for the purpose, and from which they can be extracted. M. *Dumèry* and M. *Friedmann* have pursued, each on his own part, the realization of this idea. The example of the *Beslay* boiler, proves that a good circulation may prevent the formation of incrusting deposits. But the dejectors of MM. *Dumèry* and *Friedmann* have not yet attained the object, and besides, their application to locomotives would present special difficulties.

b. by decomposition. As this previous precipitation under the action of heat cannot be obtained neither in the tender, nor in the boiler, it may be naturally looked for in chemical reactions, and effected, either in the water supply tanks, or in the boiler.

The reagent varies according to the nature and proportions of the predominating salts.

102. *First class. Previous purification.* — The mode of separating the deposits varies also; with great surfaces of reservoirs, decanting is sufficient. If, on account of local conditions, the spontaneous formation of the deposits cannot be waited for, filtering is adopted.

At *Aigrefeuille* (line from *Niort* to *la Rochelle*), where the water, obtained from a well 197 feet deep, is very calcareous, the reagent is milk of lime, which precipitates the preexisting carbonate to a great extent, with that which arises from the saturation by carbonic acid in excess. Simple decanting is sufficient.

On the Thuringia line previous precipitation is considered necessary, as the proportion of the earthy salts reaches 0,0003. The water pumped up, introduced into large basins, and heated to 86°, receives first lime water, then carbonate of soda dissolved in hot water, the proportion of each of the reagents being determined by a previous analysis of the deposit formed by the natural water. After agitation, the water is allowed to rest for nine hours.

The carbonate of soda decomposes the sulphate of lime; the alkaline sul-

(*) M. *Wagner* proposed at first to carry the feed-water to the boiling point in a special receptacle by means of the exhaust steam; then he arrived by successive modifications, at the almost exact reproduction of *Schau's* apparatus.

phate remains in solution. An excess of soda must be avoided, as it would render the water viscous.

As soon as the water is clarified, it is decanted; the deposit is extracted through a special opening, and the operation commences afresh. The analysis of the residue of the evaporation to dryness of the clarified water, shows that, under these conditions, the sulphate of lime alone is completely precipitated; the carbonate is only so in the proportion of about 70 per cent.

Filtration. To the ordinary enemy, the carbonate of lime, the reagent opposed is almost always lime-water. But when just enough is added (and this must be done) to saturate the carbonic acid in excess, the salt remains for a length of time in suspension in a floculent state, and if the daily consumption is considerable, the reservoirs would require to have a considerable surface, which is not always possible. Some arrangement must then be made for hastening the formation of the deposits.

There is a very simple means of greatly hastening the precipitation, viz. to exceed the point of saturation. By trying this in a flask, the precipitate is seen to form more rapidly, and the test-paper shows a greater excess of lime; but the remedy would be worse than the evil. This fact has been ascertained at the Southern Railway depôt at *Vienna*. The deposits formed by the lime in excess, seem to be much more adherent than those which are formed in the water without this addition. Strict saturation must thus be adhered to, by starting the operation, when space is wanting, in a more expeditious way than by the action of the difference of the densities.

Such was the case at the *Süd-Bahn* depôt at *Vienna*, which consumes daily 10.500 cubic feet, taken from wells sunk to the subterranean sheets of water which flow into the *Danube*; this water contains, according to the analysis of M. *Steingl* (*):

Carbonate of lime	0,027510	
Do of magnesia	0,016562	
Sulphate of lime	0,008971	
Chloride of sodium	0,011459	0,082532
Sulphate of soda	0,000373	
Silica	0,001090	
Oxide of iron and alumina	0,000145	
Organic matters	0,016420	
Water	99,917488	
Total	100,000000.	

(*) M. *Gottschalk*, Memoirs of the Société des Ingénieurs civils, 1873.

The consequences of using such water were very soon evident.

"The incrustations which resulted from it in our boilers had, during these latter years" says *M. Gottschalk* (*), "become so considerable and so adherent, that at the end of "some months of service, in spite of repeated washings out, the space between the tubes, "that between the stays of the fire-box sides, and that between the roof girders, were "soon stopped up. The consumption of fuel became greater and greater, and the "boxes being burnt were destroyed in three years or three and a half, while they last "from ten to twelve years on the other parts of the line."

It was necessary to take some step.

Not pretending to purify the water completely, the most abundant salts only are dealt with, those most injurious by the mass, if not by the adherence and the hardness of their deposits; that is to say, the earthy carbonates; nothing then is added but lime water, in such a proportion that the alkaline reaction is not reached; and as space was wanting in order to establish depositing basins, filtering was adopted.

The mixture of the water and lime-water is driven by a pump in to cylindricalfilters, about 3,25 feet in height and about the same in diameter. Six of these apparatus aresufficient for the daily expenditure of 10,500 cubic feet.

The filtering material is formed of successive layers of carpenter's shavings and coke refuse. A strainer is placed at the bottom of the cylinder, and the latter filled with the filtering material, which is forcibly compressed by a cover. The water coming from the mixer, is driven into the reservoirs, passing through the filters; it enters them at the top and goes out at the bottom, by a pipe ending in the ascension column. The filters are emptied every week; and the material can be washed, and used over again. When a filter is opened, after having acted for some days, the upper part is found to be the most charged with calcareous matter, as is quite natural. But there is also found, above the filtering material, which is greatly compressed, a thick layer of calcareous matter; doubtless the formation of this thick deposit is due especially to the fact that the mixture, traversing to that point tubes of small diameter, carries along by its velocity, precipitates already formed, and which separate on entering the cylinder, where the mixture abruptly loses its velocity. But perhaps also the calcareous matter already deposited, itself acts as a filtering material.

The apparatus for purifying the depôt water at *Vienna*, established by M. *Bérenger*, acts very well. Applied to an already existing arrangement, it does not present the methodical character of one single and complete plan, but it

(*) M. Gott-chalk. Memoirs of the Société des Ingénieurs civils, 1873.

seems to have much improved the position of affairs. The expenses of the operation amount to 0,086d. per cubic foot, the expenses of establishing not included.

"We have always", says M. *Gottschalk*, "round the tubes and on the sides of the fire-box, deposits arising from our only precipitating the carbonate and not the sulphate of lime contained in our water. But it is positive that these deposits are formed in a very slight proportion, that they are not adherent as previously, and can be easily removed by well washing out the boiler."

To get rid of the sulphate of lime also, a second distinct operation would be necessary, with carbonate of soda or chloride of barium as re-agent.

103. *Second class, substances introduced into the boiler.* — Certain salts, particularly the carbonate of soda, and the chloride of barium have been, and still are employed: the first for water containing carbonate or sulphate of lime, or both; the second for water loaded especially with sulphate of lime. Their effect being to precipitate the carbonate of lime, and of the sulphate of baryta formed from the decomposition of the sulphate of lime, it may be asked at the first blush, what is the use of determining by re-agents, the deposit in the boiler of precipitates of the same nature (save the substitution of the sulphate of baryta for the sulphate of lime) as those which would form therein of themselves; in what, particularly, is the carbonate of lime, precipitated artificially, less injurious than that which is precipitated naturally. It is that the injurious action of the deposits does not depend only on their nature and their bulk, but also on the conditions under which they are formed, and which modify their physical state, their adherence, and their hardness. Besides, the decomposition of the sulphate of lime, so often found associated with the carbonate, with which it forms the hardest and the most adherent deposits, may on that account be useful. We are far from believing moreover, that the two re-agents in question, particularly the carbonate of soda, have been, and are always appropriately employed.

Among other substances, some (for example clay and talc) are inert, without chemical action on the salts which form the deposits, and may, at the very most, act mechanically, by mixing with the salts and preventing them from adhering, either to themselves, or to the metal surfaces. Others appear to have more than a simply preventive action; they disaggregate the deposits already formed, and reduce them to a sort of mud, which can be cleared out by washing.

Others, lastly, like cachou, have also a chemical action. This juice, extracted from the *acacia-catechu*, and often recommended as a tartrifuge,

seems to act by the tannin which it contains. The tannic acid decomposes the earthy carbonates, and gives salts which are insoluble but by no means dense, easily kept in suspension by the boiling, and not adhering to the surfaces; but it is without action on the sulphates, and it attacks iron. Cachou has given good results on divers lines, on the Rhenish railway among others; it is however very little employed nowadays, especially on account of the viscosity which it gives to the water. The result is the same, and on the same grounds, with bark, wood, molasses, beet-root, potatoes, sawdust, etc., which have been frequently tried with more or less success. As to fatty matters, particularly tallow, which is often recommended as preventing the cohesion of the deposits, we have pointed out (97) what risk is incurred, with calcareous water, by trying to take advantage of this property.

The following, as example, is a composition which was in favor twenty years ago on the railways in the neighbourhood of the Rhine:

Cachou	3
Glauber's salt	2
Carbonate of soda	2
Common salt	3
Water	68 to 70

After each cleaning out, 9 lbs. of this solution were put into the water.

A substance which is efficacious for one sort of water, may be without value for an other sort. This does not however prevent people continually urging receipts as possessing a general virtue, which have succeeded in some particular cases, and perhaps only just so at the very most; and if these recipes have for the most part been given up, the reason is that to no efficacy or a very unequal one, they almost always join the disadvantage of rendering the water frothy, and dirtying the cylinders and the slides.

As is the habit in questions of this kind, the same groove is always continued in. A receipt is recommended, tried without success, and given up. Years pass by, the failure is forgotten, the same receipt re-appears as a novelty, and always accompanied by unexceptionable certificates. Such is the case with talc, with glycerine, which have latterly again turned up.

As for talc, which like clay is absolutely inert as has often been pointed out, what can be its action, and does it really form with the salts mixed deposits which do not encrust? But before trying to explain the fact, it is as well to wait until this should be proved; tried in locomotives a dozen or fifteen years ago, talc was declared at that period to be of no efficacy, an opinion borne out by the trials made quite recently on the Eastern of France.

As to glycerine, it is said to act : 1st, by increasing the solubility of the sulphate of lime, with which it is said to form a compound soluble in water; 2nd, by forming, when the point of saturation of the water is reached, a gelatinous precipitate excluding all adherence, and resisting besides the mechanical carrying over of the solid particles by the steam. M. *Asselin's* glycerine is produced by the saponification of the residues from railway-grease. He gives 2,2 lbs added at once for 3 or 4 tons of water, every fifteen days or a month, according to the conditions of the service, and the degree of impurity of the water.

The glycerine that he employs is not pure; it is always mixed with a quantity of chloride of barium, variable according to the case. It is quite natural that the composition of the re-agent should vary according to the composition of the salts in solution in the water. It will be remarked at the same time that according to the author himself, one of the elements, the glycerine, acts with respect to the sulphate of lime as solvent, and the other, the chloride of barium as precipitant : a double action which does not appear to conduce to the clearness of the process.

Some trials made on the Northern as well as on the Eastern of France gave results, which, if not absolutely negative, were at any rate anything but marked. If some stationary boilers seem to show a little more favourable results, nothing warrants a return to glycerine, in the case of locomotive boilers, with which only we have to occupy ourselves.

An apparatus called the *magnetic anti-incrustator* has been tried in England and in the United States; sometimes, we are assured, with the most complete success, sometimes without any result : the inventors being unable to explain either the one fact or the other. The effects being as capricious, to say the least, as their explanation is obscure, there is no occasion to dwell on the subject. Altogether, the serious question of incrustation has not hitherto made one step forward, although a return to the old practices up to a certain point may be warranted in spite of their small chance of success and on the ground of more ample verification; and previous precipitation, before the introduction of the water into the tender, appears to be the only course to pursue; whenever the water cannot be employed in the pure state.

104. *Aero-steam.* — It was long ago imagined, to suppress all intermedium between the burnt gases from the fire and the water to be evaporated, by injecting these gases into the very mass of the water. M. *Dœlen* made some trials in this direction, but without success. More recently,

Messrs *Fox* and *Walker*, of *Bristol*, have tried to carry out the same principle under a different form. The fire-box is closed : the air is forced into it, and all the products of combustion are themselves driven into the boiler. Like the others, these attempts also failed.

M. *Furno*, running foreman on the *Orleans* line, recalls a curious application of the driving of air into the boiler, to which drivers had recourse formerly :

" We all ", he says (*), " know that a score of years ago, at a time when locomotive " engines were less perfect, and the driving of them less easy, intelligent enginemen, " when their pressure failed, and they feared being uable to bring in or start their load, " profited by the power of inertia of the train, to send into the boiler by running with " reversed gear, the necessary quantity of hot air from the fire-box, in order to get " up the required pressure on the manometer."

Vis viva was thus stored up, during the slackening of the speed, in order to facilitate starting afterwards, whether forwards or shunting.

Mr *G. Warsop*, of *Nottingham*, injects a certain quantity of air into the boiler, not occasionally and by means of the inertia, but regularly, by taking this work from the pistons; and the air which he injects is not taken from the smoke-box (as that involves disadvantages, to which we shall return when treating of counter-steam), but from the atmosphere. Trials have been made in England, on stationary engines, and on a locomotive on the Lancashire and Yorkshire. A single action air-pump, 6 inches in diameter, and with 2 feet stroke, is placed under the boiler, and driven directly by one of the cross-heads. The air-piston thus works constantly; it is by acting on a system of levers on the suction-valve, that the driver interrupts the working of the apparatus, when required.

A special manometer is placed under the eyes of the driver, beside the steam manometer, and is joined to the force pipe by a small tube. The air compressed by the pump circulates through an iron worm-tube placed in the smoke-box, where its temperature is carried to about 600° F., and whence it passes into a tube placed at the bottom of the boiler, pierced with a multitude of small holes. The greater portion of the work expended by the pump being at the same time converted into heat, which is employed chiefly in heating the air, the latter already possesses a high temperature, and on that account, can be forced directly into the boiler.

(*) *Bulletin mensuel de la Société des anciens élèves des Écoles d'arts et métiers*, 1873, p. 203.

The object is first of course to economise the fuel. This has been attained, it is said, with again exceeding 9 per cent. But everybody knows that in experiments, an economy is very often shown at the commencement, and all in good faith, which is by no means to be found in regular practice. When an engine is arranged for an experiment, it is put it into perfect order for the occasion; so that either in comparing it with itself, or with others, the general improvement has a certain unknown, but more or less considerable effect.

In the present case, the economy would be explained by a double effect: on the one hand, the partial utilisation of the heat of the gases of the smoke-box, taken up by the air, and restored thereby to the boiler; on the other, the mechanical action of that air on the water, the cohesion of which is thereby overcome, and the ebullition facilitated. These two effects are said to far more than make up for the passive resistances of the pump.

The mechanical action of the air on the ebullition would thus constitute the principal mechanical advantage of the system, and the essential cause of the economy, if there be any. We know that water deprived of air, and not agitated, enters into ebullition at a temperature much more elevated than that which corresponds to its pressure, and that a very slight proportion of air is sufficient to set that resistance free. Each bubble of air, becomes as it were, a furnace for the formation of steam. The advantage which there would be in forcing this proportion, offers thus nothing absolutely improbable, although in a running locomotive, the movements and joltings of the boiler would reduce the influence. Perhaps it is difficult to admit that the same quantity of heat thus transformed with inevitable losses, into the mechanical work of the pump, can it be more efficacious for the separation of the molecules of the water, than if directly applied thereto. But this work is employed almost wholly in the separation in question, without at the same time producing any rise of temperature. It would seem then to us imprudent to condemn the process by *a priori* arguments, which have been so often refuted by experience, that they should be made use of with more reserve.

One question which presents itself at first sight is this : what will become of feeding by the injector, which is still more indispensable to locomotives, than to any other engine? It appears well established, that for the slight proportion of air, indicated by experiment as the most favourable to economy, the two operations work well together, but when the regulator is open.

M. *Regray*, locomotive engineer of the Eastern of France justly thought, that M. *Warsop*'s idea deserved thorough investigation, less perhaps by

the importance of the direct economy of fuel, than by interest in the effects at work. Their attentive and continued observation will perhaps lead to unexpected and useful results, touching the maintenance of boilers. He thus at first deputed, M. *Dieudonné*, engineer, to follow out the experiments undertaken in England.

" We have ", says M. *Dieudonné*, " followed up two trains on the engine 369. The first " was a passenger train. It was running at a mean speed of 37 miles an hour, with a " load of about 100 tons. 19 miles were run without stopping. The apparatus was act- " ing all the time. This rapid run over a long length, without stoppage, was a very " severe test. In effect, the quantity of air introduced in the unit of time, as well as " the heating and other effects were thus brought to a maximum. Nevertheless the " feeding by the *Giffard's* injector acted perfectly. The engine has no pumps; it has " two small *Giffard's* injectors, placed vertically, with the nozzle very low, on the level " of the foot-plate. One of them fed the whole time. Its delivery corresponded to the " expenditure of the engine.

" The gauge-glass showed no abnormal agitation. The oscillations of the air mano- " meter were, at the most, one atmosphere in amplitude.

" The air-pump remained cold, but the tube through which the air was forced was " much heated. The temperature of the air, indicated by a pyrometer, was 590°, im- " mediately after stopping. The engine did not prime at all, and the steam pistons, " lubricated by an automatic lubricator, showed no signs of heating.

" The second train was a goods one, at a speed of 22 miles an hour, with stoppages, " and shunting at some stations.

" We have pointed out that the *closing of the regulator is always accompanied by* " *the stoppage of the Warsop apparatus*, doubtless in order not to introduce indefinite " quantities of air into the boiler.

" The feed, during this journey, was intermittent. The *Giffard's* injector was several " times started while running, during the working of the apparatus. The starting did " well, excepting once, and then it was sufficient to shut the *Warsop* apparatus for a " minute, but it was put on again as soon as the injector worked."

The experiments made on the engine of the Lancashire and Yorkshire railway, decided the company to apply the aero-steam to six other engines. If the advantages were as marked, and as well established, as is asserted, surprise may be felt that the trials should be restricted to one single line, out of the vast system of lines in Great Britain. But in such a matter many examples warrant a certain amount of scepticism; and it is natural enough to wait for the confirmation of the success announced by those who have taken the initiative in the trial.

The question would be in this case, of a kind of engine with a mixed *intermedium*, steam and air, if the latter were in a less insignificant proportion; and we speak of it while on the subject of incrustation, because in this

respect chiefly, it appears to have given, at least in certain cases, and with certain water, positive results; so that if the injection of air into the boiler ever comes into practice, it will perhaps be as a preservative means against incrustation.

According to the details given on this point by Mr *G. Eaton* on the 10th of August 1872, at the *Brighton* meeting of the Mechanical Section of the British Association, the application of aero-steam to the locomotive of the Lancashire and Yorkshire railway effected, not only the radical suppression of adherent deposits, but even the disappearance of those which had been formed when the apparatus was not acting. The opinion has even been expressed that it might go to far, and prevent the deposit of the slight pellicule which exercises a preserving action on the surfaces without any appreciable opposition to the transmission of the heat.

The great agitation imparted to the whole mass of water may explain this immunity up to a certain point, still it is difficult enough to admit that the increase of agitation due to the air should have an action intense enough to prevent the adherence of the deposits formed during the periods of rest, when the water is consequently stagnant, and yet more difficult to explain another advantage attributed to the injection of the air: the almost complete suppression of the carrying over of water by the steam. If the facts observed in England by M. *Dieudonné* are not sufficient to decide the question, and if the discussion of the circumstances under which the saving of fuel have been observed, prevent our looking on them as fairly due to the apparatus itself, the general tendency is at least favorable. The Eastern of France Company thus thought proper to re-introduce this interesting experiment.

The *Warsop* apparatus was set up on an engine with six wheels coupled, of the Eastern of France. The worm-tube of the smoke-box was suppressed for greater simplicity, so that the elevation of the temperature of the air at its entrance into the boiler, is due only to the compression. M. *Dieudonné* found, by means of a small collar of fusible metal applied to the forcing tube, that the external temperature thereof was from 212° to 230°. The inside temperature was of course very much greater, the pipe being very thick, but without reaching that of the smoke-box, so that the utility of the worm-tube is something; but it depends on the quantity of air introduced, which under the admitted conditions is so slight, that the heat taken thereby from the gases, and after the heating by the compression, would be insignificant.

During a period of six months (September 1873 to April 1874) the engine

did its work without any incident, no refusal to work of the *Giffard's* injector, and no gripping of the air pump. It is not sufficient that, at the outset, an innovation should bring with it neither disadvantages nor fresh difficulties, there must be advantages. Whether the aero-steam has any of the latter, will be known later on. Perhaps experiments may prove that it increases the power of the engine; and that would be by no means a matter of indifference.

The engine provided with the apparatus certainly consumed during the indicated period, a little less than the average of similar engines doing the same work; but the difference is of the order mainfested in comparisons made between identical apparatus.

As to the anti-incrustation action, the actual conclusion is quite negative. The engine having come into the shops for ordinary repairs, advantage was taken to examine the tubes; and it was then ascertained that the effect of the apparatus in that respect at the end of six months was nothing. In the continuation of the trial the results come out more clearly.

The question offers enough interest besides for us to have no hesitation in reproducing the abstract which M. *Regray* has been good enough to communicate to us, and in which are developed the considerations which decided him upon his investigation of the subject.

" Before proceeding for ourselves to special experiments, we were bound to investigate " the chances of success which they might offer, by a study of the principles of the appa- " ratus.

" The economy of fuel attributed to the *Warsop* system would arise from three causes.

" 1st. The heat communicated directly to the boiler by the hot air, which heat is " partly taken from the gases of the smoke box;

" 2nd. The more active evaporation from the surface of the tubes, no longer covered " with incrustation, a consequence of the mechanical action of the air;

" 3d. A less amount of condensation in the cylinders.

" We shall at first proceed to calculate the quantity of heat directly introduced into " the boiler by the hot air, which enters at 590°.

" Let us first find the weight of air forced in per revolution.

" The volume of the pump is 0,39 cubic feet.

" By diagrams, the volume of air, at the atmospheric pressure, drawn in by the piston " at each revolution, is ascertained to be 82 per cent of the volume of the pump.

" The weight of this air is thus $0{,}82 \times 0{,}39 \times 0{,}0807$ lb. $= 0{,}0256$ lb.

" The calorific capacity of the air, at a constant volume, is 0,1687. Thus the quantity " of heat introduced by the air, at each revolution will be:

$$0{,}0256 \times 558^{\circ} \times 0{,}1687 = 2{,}39 \text{ units.}$$

" Let us find out, on the other hand, what is the quantity of heat expended by the " engine, per revolution.

"Let us suppose the admission to be 30 per cent, and the weight of water carried over "equal to 25 per cent of the weight of the steam.

"The volume of steam expended per revolution will be:

$$0.785 \times \overline{1.25}^2 \times 2.00 \times 4 \times 0.30 = 2.90 \text{ cub. feet.}$$

"The steam being at about 10 atmospheres absolute tension (356°), the heat con- "tained will be

$$2.90 \times 0.137 \times (1091.7 + 0.305 \times 324.6) = 464 \text{ units (*).}$$

"Adding the heat contained in the water carried over:

$$2.90 \times 0.137 \times 0.25 \times 324.6 = 31.8 \text{ units,}$$

or, in all 495.8 units of heat.

"The loss, by the void spaces, would increase this figure still further.

"We may thus admit that the boiler expends 496 units of heat, at least, per revo- "lution:

$$\text{Now, } \frac{1.17}{495.8} = 0.00237.$$

"The quantity of heat introduced into the boiler by the heat proper of the air, is thus, "only between the two and three-thousandth part of the heat expended by the engine.

"It is thus not in this particular that the *Warsop* apparatus can produce an appreci- "able saving of fuel; and in this respect, we quite agree with a criticism of the apparatus "which appeared in *Engineering* in August 1872.

"We do not indeed rightly understand the object of the worm-tube placed in the "smoke-box. In effect, the compression of the air to 10 atmospheres ought to raise its "temperature to 356°, if this air is not cooled by any external cause. In fact, we have "ascertained that the air reached a temperature of from 302° to 382° at the entrance of "the forcing tube; its passage through the worm-tube in the smoke-box, ought thus "only to heat it from 302° to 382°. After what had been stated to us, it should have "been ascertained that by increasing the number of spires of the worm-tube the "economy of fuel would be increased. If this fact is exact, we attribute it, not to the "increase of the temperature of the air, but to the greater expansion thereof, which is "a consequence of the increase of temperature. It may be that the more the air is expan- "ded, the more efficacious is its mechanical action on the activity of the evaporation.

"For us, in effect, it is by this mechanical operation alone, that the *Warsop* apparatus "can produce any appreciable results.

"When a current can be established, which renews the water in contact with the

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(*) In reality, this figure represents the heat necessary for the formation of the steam, but not that which it contains. The latter is per lb. (114) not $\lambda = 1091.7 + 305 \times 324°.6$ but λ decreased by the external work (A*pu*) produced by the formation of the steam, that is to say $\lambda - 83 = 1008.9 + 0.305 \times 324.6$. On the other hand, for the specific weight 0.137 lb. of saturated steam t 356°, it is desirable to substitute the much more exact figure 0.149 lb. given by M. *Zeuner's* table. These corrections give 266 units of heat instead of 258, a difference which is however of no consequence for the approximate calculations dealt with in M. *Regray's* abstract. It is the same thing as regards the following calculation of the work of the steam according to the old formula.

" metal surfaces unceasingly, as in the *Field* boiler, there would infallibly result a " better utilisation of the fuel, or a reduction in the weight of boilers. The air driven " in by the *Warsop* tube, would have, it is said, this effect, and there would result from " it a greater production of steam, with the same consumption of fuel.

" It is also stated that the driving in of the air prevents the deposits from adhering " to the tubes, and consequently the boilers would be kept very clean, from which would " result an additionul economy of fuel.

" We have no positive reasons to set against these statements. Let us only remark " that as the very movement of the locomotive in running powerfully and unceasingly " shakes the mass of water, it is the locomotive that has less need of a special apparatus " to increase the activity of evaporation.

" It is said, lastly, that the presence of a small quantity of air in the cylinders, reduces " the amount of condensation therein. This is very possible. At the same time we con- " sider it quite natural, that engine No 369, taking its steam so high up, with all the " induction pipes inside, should not prime.

" It is interesting, in order to complete this investigation, to calculate the amount of " force absorbed by the action of the pump.

" Let us consider the engine at the velocity of 22 miles per hour, that is to say, making " two revolutions per second. The surface of the pump piston is 0,19 sq. ft. Diagrams " show that the pressure of the air would reach by the forcing to about 1 atmosphere " over the pressure in the boiler. Thus the work, in forcing in the air, for each stroke " of the pump, will be:

$$10{,}000 \times 0.19 \left\{ 10 \times 0{,}06 \left(1 + 2{,}30 \text{ log. nat. } \frac{0{,}60}{0{,}06} \right) \right\} = 2560 \text{ ft. pds.}$$

" and adding 10 per cent for the friction of the piston : = 2816 ft. pounds.

" There are two strokes per second, thus:

$$\frac{2 \times 2816}{550} = 10 \text{ horse power.}$$

" represents the work absorbed by the air pump.

" Let us calculate, on the other hand, the work furnished by the engine to the driving " shaft, supposing the admission to be 30 per cent, and the useful effect 70 per cent (sur- " face of the piston = 0,19 sq. ft.)

$$\text{" } 2 \times \frac{1}{75} \times \frac{70}{100} \times 10{,}00 \times 4 \times 0{,}19 \left\{ 9 \times 0{,}1827 \times \left(1 + 2{,}30 \log \frac{100}{3} \right) \right\} = 318 \text{ horse power.}$$

" The pump thus absorbs $\frac{10}{318} = 0{,}031$ of the total work. As we have seen on the other " hand, that the quantity of heat brought back by the hot air does not exceed three " thousandths of the total heat expended, it seems to us proved that the *Warsop* apparatus " can only produce economy by the mechanical action of the air forced in, an action " which besides escapes calculation.

" The result, for us, is that the circumvolutions unparted to the air in the worm tube " in the inside of the smoke-box, being unable to produce any influence on the economy " of fuel, we have suppressed the worm-tube, and made the experiments under the fol- " lowing conditions.

"Engine 093, provided with *Warsop*'s aero-steam system without worm-tube, was "put in service at the *Troyes* dépôt on the 19th October 1873. Since that period, it has "run goods-trains between *Paris*, *Troyes*, *Chatillon* and *Chaumont*, like the other "engines of the same series, attached to the *Troyes* dépôt.

"From October 1873 to April 1874, engine 093 ran 9.719 miles without the working "of the *Warsop* apparatus having in any way hindered the general running of the engine. "The *Giffard's* injectors acted very well, even the ordinary one, which is not put on. The "air piston required nothing done to it.

"After a continued service of 6 months, the engine came in to the work-shops of the "dépôt, for small repairs, and its inspection was proceeded with.

"In October 1873, when it was turned out of the great worksheads engine 093 had "a new set of tubes.

"Five tubes, at sufficient distances to represent the general state of the set of tubes, "were compared with other tubes, which had been placed in new, and as term of com- "parison on the 19th October 1873, in another engine of the same series, and doing the "same work (the 079).

"It was impossible for us to detect any difference between the tubes of the engine 093 "and of the engine 079. The tubes of both were covered with a slight coating "of tartar. Thus, the effect of the aero-steam, from the point of view of incrustation "was nothing.

"As to the consumption of fuel, oil, etc., the following are the figures referring to the "whole period (October 1873 to April 1874):

"1. Fuel per mile: for engine 093, ...	72,113 lbs
"For the other engines of the same series doing the same work ;.....	72,675 lbs.
"2. Oil etc. per mile: for engine 093.....	0,0706 lbs.
"For the other engines of the same series doing the same work :.....	0,0703 lbs.

"Thus, the air pump consumed very little for its own lubrication.

"As to the economy of fuel brought out by the above figures, it is so slight, that it "may well be attributed to other causes than the aero-steam. In any case, we are far "from the 12 to 13 per cent stated to have been found in England.

"The results of this experiment, little conclusive although they be as to figures, seem "to us, however, to deserve attention.

"The force absorbed by the action of the air-pump, may be, as we have stated, esti- "mated at about 10 horse; that is nearly $\frac{1}{10}$th of the total force of the engine itself. Now, "from the figures quoted above, it results, that the mean consumption of the engine, "provided with aero-steam, was equal, if not lower, than that of the other engines of "the same type, not provided with that apparatus.

"We ought to conclude from this, that if the injection of air was without effect on the "apparent incrustation of the tubes, it must necessarily have had an effect, either on "the more rapid evaporation of the water, or on the condensation of the steam inside "the cylinder; one of these causes, or both combined, enabled an increase of work to "be put on the engine without increase of expense."

"Paris, 5th June 1874."

§ VII. — On the suppression of smoke.

105. The smoke which passes off from the fires fed by certain coals, with very rapid distillation, is often most seriousa disadvantage to the neighbourhood where there are industrial works.

If it is not always easy to avoid the production of smoke, it may at least be much reduced by proper attention to the fire, and by only requiring from the boilers a moderate production of steam. In their report on the competition opened for the best steam-boiler, MM. *Dubied* and *Burnat* (*) expressed themselves thus:

"If the numerous inventors of smoke-consuming apparatus were to visit *Wesserling* "works, more than one would leave his illusions behind him there, after the examination "of boilers which have ordinary grates, and which do not smoke, or only allow rarely, "a very light smoke to be seen over them. The proprietors did not wait for the invita- "tion of the authorities; and if they do not produce smoke, it is, because they prefer "not to do so."

The coal employed at *Wesserling* comes from *Saarbrücke* and *Ronchamp;* and is therefore very smoky.

As long as the public were not seriously affected, and the suppression of smoke seemed to present great difficulties, the authorities could not but allow a certain indulgence, dictated by the interests of industry itself, its development and its progress; they only interfered in the case of evident necessity, to insist either on the exclusive use of coke, or on the construction of chimneys of a much greater height than that required for the draught, and that with the object of letting the smoke into the atmosphere, at a height sufficient to render it almost inoffensive; by degrees, these arrangements have become less necessary, owing to the progress of the question; and if, since the inauguration of the regime of 1865, the exercise of the initiative, which legally belongs to the agents of the Government has become very restricted (**), it is partly at least, because the weight of the evil has diminished.

(*) *Bulletin de la Société industrielle de Mulhouse,* 1860.

(**) One observation, however, on this point. Civil process can always be had recourse to after friendly arbitration has failed; but there are circumstances in which it can hardly be relied on. Between a great company, for example, for whom a lawsuit, carried at need through all the degrees of judicature (affording occupation for the courts), and a private individual for whom a lawsuit

The decree of 25th January 1865 has (art. 19) "that the fire-box of boilers "of every category ought to consume its smoke". This regulation, inserted in a section applicable only to stationary boilers, does not reach locomotive engines; but they are, like the others, subjected to the obligation laid down for them by the Schedule of conditions for concessions, "to consume their smoke" or, more correctly speaking, not to produce any: for, smoke once produced, there is nothing more difficult than to "consume" it.

This clause appeared, for a long time, to involve the use of coke (13) as a necessary consequence; a condition accepted besides, without objection by the great railway companies, because coke was generally regarded as the only fuel appropriate for the abundant and regular production of steam in locomotive boilers with small fire-boxes, and as the most favourable to the economical maintenance of these apparatus. It was known however, by sufficiently numerous examples, that the use of the coal itself was possible, at least abstraction made of the smoke, which was then tolerated; that on some lines not a single atom of coke was being burnt; that, without taking

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involves so much expense and trouble, the contest is really unequal; and in the face of the formal terms of the decree of 1865 (arts. 19 and 20) the inactivity of the authorities would be a denial of justice, if the question were one of serious damage caused by the smoke of stationary boilers. The damage in such case results of course from an *infraction* of the law, for which a prosecution should be instituted officially : an obligation which a ministerial circular of the 12th Decr. 1865, addressed to the prefects, vainly endeavours to shirk, in these terms : " If this condition (smoke-consuming) is not fulfilled, *it is the business of the neighbouring owners, who find themselves aggrieved,* to obtain justice for themselves by bringing their complaints before the courts. "

What thus becomes of art. 29 of the decree?

The circular only admits the initiative on the part of the authorities, " if, in any locality, the emanation of smoke is so great as to affect a whole quarter, and if by that same, the nuisance amounts to a public injury. "

A singular theory, according to which, isolated interests, however seriously affected, cannot profit by the protection of the law, a protection reserved for *groups*, for which only, no doubt, the authorities would think proper to disturb themselves!

The application of article 29 presents, it is true, one difficulty : It refers, for penal authority, to the law of 21st July 1856; now this latter does not provide for the infraction which results, at this date, from the non-observance of article 19 of the decree of 1865.

In the matter of locomotives, the legal position is different, but obscure. It is then question of a clause in the schedule of conditions (*cahier des charges*); what is the penal authority in that document, beyond the regulations laid down by art. 70 of the schedule itself, and by the second chapter (art. 12) of the law of 1845? No one knows; and this uncertainty does not appear to displease the authorities, who have not shown great anxiety to take advantage of the opportunities (it is unnecessary to recall them) to have the question decided judicially.

In the actual, and dubious state of jurisprudence, art. 30 of the schedule of conditions would doubtless have no other authority than art. 471 of the penal code, and it would have that authority at the same time, in common with article 19 of the decree of 1865, notwithstanding the terms of article 29.

into account wood and turf, coals and even lignite of very inferior quality were in regular use. But crude coal was looked upon as little else than a make-shift, only to be tolerated on account of the want of coal suitable to the manufacture of coke.

As long as the companies were able to supply themselves with coke without too much difficulty, and under reasonable conditions, the question hardly ever arose, in general, as to whether the exclusion of coal was supported by satisfactory reasons, and as to ascertaining the results of its use on the railways which had no option. The rapid rise in the price of coke and the impossibility which the railways nearly experienced, at a certain period, of obtaining it at any price, were required to make the necessity of getting out of such a position comprehended.

In proscribing smoke, the object of schedule of conditions, was to protect from its annoyances, not only the passengers in the running trains, but also the neighbourhoods of the stations and the depots, in which locomotives have to stand in steam. The clause, nevertheless, had especially in view the interests of passengers. It was quite natural, at the time when the necessity of carrying on a large part at least of the traction by coal, became recognized, to commence by goods trains, were it only to reduce the price ot the coke. It is of very little consequence, in fact, whether the engines coupled to these trains give out smoke in the open country; and if the disadvantages exist while standing, enhanced indeed by the greater length of the stoppages of these trains, the question was above all, to find a simple and efficient means of reducing them. This was accomplished.

Causes of smoke. — Smoke is due chiefly to the decomposition of the carburets of hydrogen, given off by the distillation of the fuel. In order that these carburets may be completely consumed, and consequently without smoke, it is necessary not only that the oxygen should be everywhere in excess, but also that the temperature should be high enough at the points where they are given off. It is necessary, in a word, to approximate as closely as possible to the conditions so completely and methodically carried out, in the *Siemens* furnace, that is to say to mix together, at a high temperature, the air and the gases, arising as much from the distillation, as from partial combustion. If not, the hydrogen alone is burnt at the moment of the decomposition of the carburets, and the carbon set free and in a very divided state constitutes the principal, or the most injurious element of the smoke, which is charged besides with hydrocarbons either in vapour, or condensed and carried over mechanically. In this state the carbon becomes very difficult to consume; thus the question is not to burn the smoke already

formed, but to prevent its formation, by burning immediately and completely the hydro-carbons, the ultimate decompositions of which give rise to it.

At the end of a certain variable time, the distillation of the coal introduced into the fire-box is complete; it is transformed into coke.

It is a question, both of producing, in general the least possible amount of smoke, and of not producing any at all, at those moments when it would be particularly objectionable. Seeing that it is after the fire has been charged, that it tends to be given off, it is also at that time that the driver ought to push the draught, and take all other means in his power to mix the oxygen in sufficient proportion with the products of distillation.

The same quantity of smoke, objectionable if it is disengaged in a mass in a very short space of time, becomes inoffensive if it is diluted in a large mass of gases. The fire-box has thus, in general at least, (for under conditions of gradients and working this rule is sometimes abrogated) to be charged frequently and in small quantities. The driver ought to avoid charging his fire at the moment of reaching a station, especially if he has to stop there, seeing that it is after charging that the production of smoke is the most difficult to avoid.

106. *Blower.* — While standing, and when the fire-box contains coal not yet distilled, which is often unavoidable, smoke would necessarily appear, on account of the stoppage of the draught. A paramount condition of the use of coal, is thus a partial re-establishment of the draught. This is the object of the blower; a small tube *t* (Pl. II *fig.* 7) provided with a cock, taking steam directly from the boiler, which it injects vertically into the chimney, through a circular opening of about 0,71 inch, either at the level, below or above the exhaust opening. (II. Pl. LIII.) The opening of the blower presumes, at the same time, the partial opening of the fire-door or of the ash-pan.

On the *Orléans* lines a blower has been adopted with several small jets (*) projecting from a ring which surrounds the variable exhaust opening, just at the level of the top of the valves *v*, *v*, (Pl. IV fig. 14 to 16). The body in

(*) This little improvement, in which, certainly, neither a new principle, nor a new form of application can be discovered, has had to contend, like many others, against those claims which under the pretext of inventions and patents, tend so often to swallow up the whole, and to screw something out of what belongs to the common fund of industrial notions. Railways especially, are the aim of this miserable speculation, so injurious to general progress and interest.

copper, 8,83 inch internal diameter, supported by two brackets screwed on *s*, *s*, is pierced with 36 vertical holes, having a total section 0,27 square inch. This apparatus appears more efficient, with the same expenditure of steam, and does not produce the same noise as the blower with a single jet.

The blower is necessary in all cases, even for engines provided with special smoke consuming apparatus; indeed, with almost any coal, goods engines require no other expedient, provided of course, that they are in the hands of careful drivers, who attend intelligently to the fire.

If, besides, the blower is particularly required during standing still, it should also be made use of during running, in order to make up for the exhaust during the descent of certain inclines.

Care must be taken that the drivers make use of the blower during stoppages. It only prevents smoke by hastening the combustion, and expending fuel; left to themselves, drivers prefer a very slow combustion, and consequently a very smoky one; hence the clouds of smoke that are often observed in stations. There is only one way of avoiding these, by fining. Drivers must be made to learn that they lose more in smoke than they gain by not making use of the blower.

The blower is very useful also for getting up steam. Opening it, as soon as the pressure reaches $2\frac{1}{2}$ or 3 atmospheres, hastens greatly the rest of the operation.

107. *Various arrangements.* — On some engines, for example those of the Great Eastern (II Pl. XXIII *fig.* 1), the fire-door is not complete. One segment remains open, instead of being closed by a register, at the option of the drivers. The object of this permanent opening, is to compel the driver to make the blower act while standing. If he does not do so, the smoke comes out partly through the door, and he receives it thus first hand. But this is a faulty expedient; it is desirable that the door should when required, be entirely closed; and, besides, the driver would be very well able to stop up the opening when it would be detrimental to the running of the engine, or annoying to himself. Let us add that during lengthened stoppages, the driver is hardly on his foot-plate at all.

For many descriptions of coal, the passenger service itself requires nothing but the addition and use of the blower. With coal from the North for example, and more still with that from *Cardiff*, the smoke is very slight and has no serious drawback, or only so by the fault of the men.

But certain coals, containing little sulphur, and yielding little ash, which are neither too rich nor too poor, and consequently neither sticking

together too much, nor breaking up into pieces, very good, in a word, for locomotives, give off too much smoke to be applied without some special arrangements, especially for passenger-traction. In the same way coal dust applied in the form of compressed fuel, and containing from 7 to 8 per cent of resin is consequently more smoky than the coal from which it is formed.

To the often little warranted pretence of avoiding smoke, most inventors of smoke consuming apparatus pretend to join another: that of producing a great economy of fuel. We know that nothing is more unfounded in general, and that in fact the minimum of consumption with a given fire-box corresponds ordinarily to the production of a certain quantity of smoke. The suppression of the smoke is obtained essentially, by an intimate mixture of the gases from the distillation of the coal, with the air, but almost always with air in too great excess. The mass of the particles of carbon which constitute the element of the smoke is insignificant. It is the one grain of carmine coloring a great mass of water. The condition of the maximum of economy is, not to *burn* the smoke, that is to say, the very small proportion of *soot* which constitutes the objectionable and visible part thereof; but to burn completely the gases, but with the quantity of air strictly necessary.

"The numerous attempts hitherto made", say MM. *Meunier* and *Hallauer*, in the work already cited, "with the object of suppressing smoke, are not encouraging; "according to the important trials undertaken by the *Société Industrielle*, it may "asserted that the results, more or less satisfactory, have always shown an increase in "the consumption of fuel, by a lowering of the return; seeing that these effects were "generally only obtained by a considerable consumption of air per pound of coal burnt."

To present the economy of fuel and the absence of smoke as incompatible would be going too far; but, in fact, they are difficult to reconcile; the condition or at least, one of the conditions of economy, is, to avoid all excess of air; while it is too often on that excess, even beyond measure, that the suppression of the smoke is founded. With 110 cubic feet of air, for example, per lb. of fuel, a sufficient proportion, or nearly so, in a well arranged fire-box, for complete combustion, the running is smoky and economical; with 240, 260, 280 cubic feet (as far as that is gone to) the combustion of the gases is complete, the smoke nothing, but the consumption of combustible, referred to the steam produced, is very considerable, the current of hot gases, at a great speed, carrying off a large quantity of heat in pure waste, unless a portion thereof be applied to heating the feed water.

Certain arrangements which succeed in avoiding smoke without introducing an excess of air, only end also in an increase of the expenditure. Such

is the contrivance invented by M. *Dumery*, and characterised by the introduction of fresh coal, by means of special distributors, under the layer of combustible, the place of which it takes, on the grate. Tried first with the fires of stationary boilers, this apparatus was afterwards tried on locomotives. If the lengthened trials made on the Eastern of France have confirmed its efficacy as avoiding smoke, they have shown also that the suppression of the smoke is obtained at the expense of the power of the boiler, which produced less steam, while burning more coal: a result which has nothing contradictory in it: the absence of smoke in no way implying, in the apparatus in question, complete combustion. In place of failing by excess of air, as do the most part of the other apparatus, this one failed for the want thereof, and that may be worse still. The influx of air, sufficient at the point where the smoke can be formed, that is to say on the coal newly put in, is not so, higher up, and the combustion of the gases is not complete. The stoking was besides very difficult and trying; the distributors acted badly by accumulating the coal against the sides of the fire-box, and the fireman had constantly to bring them towards the middle by means of a curved fork; often, indeed, he had to charge the fire directly through the door, which was negativing the principle.

Excepting this apparatus, which there is no occasion to dwell on longer, seeing that experience has not been favorable to it, all the others are founded on the same principles: 1st, direct admission of a certain quantity of air above the layer of fuel; 2nd, mixture of this air with the gases, on account of the great distance they run, and especially of a *conflict of currents*.

Nothing can be more varied than the arrangements tried, and the degree with which they attain the object. It will be sufficient to point out the principal, and above all the simplest of them. Amongst those in which simplicity is wanting, we shall make exception only in favor of one, because it is the most efficaceous of the whole : M. *Tenbrinck's*, which is very efficient, but it is doubtfulif there exist many coals refractory enough to require its use, to the exclusion of less complicated means.

In several engines with *Belpaire's* fire-boxes (Pl. I, *fig.* 4), the admission of air presents a peculiarity. The register g, uncovers an opening made only in the outside plate of the large door. The air is thus introduced between the two plates, is there heated and arrives at the fire below the inside portion i which does not go down as far as the bottom.

M. *D. K. Clark*, who has described in his work(*), the processes tried in

(*) *Railway Machinery.*

England up to 1860, gives the preference to this one : the air is injected above the combustible by a certain number of hollow stays, opened at will.

So far there is nothing peculiar. But Mr. *Clark* had the idea of placing in each of the stays, which are about 2 inches in diameter, a little nozzle 0,063 inch in diameter, out of which to discharge a jet of steam taken from the boiler. The action of the steam appears to be mainly mechanical; but it is very favourable, both to the draught of air, upon which it acts as in the exhaust (111 and foll.), and much more still to its mixture with the gases from the distillation. Experience has shown that the injection openings, first placed on the lateral sides, are more efficient on the front and back sides. The opposition of the two systems of jets at the same time produces eddies which are very favourable to the mixture. A cock regulates the injection of the steam.

The arrangement most adopted in England, where it is often completed by others, consists in admitting the air through the fire door; and deflecting it by means of a small sheet iron screen (II. Pl. LXXV, *fig.* 4 *a*), as much to avoid its direct, and consequently cooling action on the tube plate, as to mix it with the gases, and with the air coming through the grate.

M. *Friedmann's hood.* The much used principle of the deflector has been reproduced by M. *Friedmann*, but by carrying it to excess; in his hands, the reflector has become a sort of great reversed basket in sheet iron, applied against the hind plate, above the door. A double row of air tubes provided with clacks placed below the basket serve, when required, to assist the fire door in the admission of air above the fuel.

With such dimensions, the effect of throwing down and deflecting the air introduced by the door, is evidently more marked. The inventor attributes further to this mass of metal another essential part analogous to the brick arches adopted by some inventors : of contributing, by the heat stored up, to the previous heating of the air; the considerable thickness given to the side, especially at the lower part where it was formed of a triple thickness of plate of 0,59 inch, had, is was stated, for object, the increase of this useful action. The apparatus was incontestibly smoke consuming; but in increasing the effect of the simple deflector, the apparatus was at the same time rendered impracticable : as what was burnt was mainly itself.

In the trials made on the Eastern of France with *Saarbrücke* coal, the smoke was avoided on condition of keeping the door open, and wide open, as long as the distillation of the coal was not complete. Immediately an attempt was made, before that was done, not to shut the door, but only

to hold it ajar, the smoke appeared. Once the transformation into coke effected, the door could of course be shut with impunity as regards smoke. But in that case, the hood went to a red heat and rapidly burnt.

It is without doubt to combat this rapid and inevitable corrosion of the metal, plunged into the midst of flame, without having one of its faces cooled by water, that the thickness, especially at the lower edge was gradually increased, as it was that which the oxidation ate away with extreme rapidity. The final destruction was thus delayed on account of the greater mass of metal to destroy, but nothing could be done against the effect itself.

Before M. *Friedmann*, M. *Stässger* had already introduced sheet iron diaphragms into the fire-box, but these have been given up, on account of their extremely rapid burning.

The admission of the air in great excess during the period of distillation must have besides involved a considerable increase in the consumption of the fuel; but it was chiefly the apparatus itself which was consumed. Metallic diaphragms placed thus in the hottest region of the fire-box are only possible under the form of water spaces; and if not so, recourse must be had to incombustible and refractory material, always cumbersome, and kept up with very great difficulty.

In the engines of the *London* and South-western, Mr. *J. Beattie* applied the two solutions, by combining a cross inclined water space (midfeather) starting from the middle of the grate, with two brick arches. Openings were made in the latter for the circulation and the mixture of the gases, and of the air admitted by two doors one above the other, which served also for charging the two compartments of the fire-box. Experience has condemned all these quite unnecessary complications, which disappear with if not before their authors. An amount of complication in the construction of the boiler proper is certainly objectionable, but it may be warranted by positive advantages. To complicate the stoking of the fire, and due working of the engine (and such is the effect of those brick introductions which block up the fire-box) is objectionable quite in other ways.

In France the apparatus most frequently applied to locomotives is M. *Thierry's* (Pl. II, *fig.* 8 to 12). It proceeds, as usual, on an upper admission of air, but combined with an injection of steam, the essential function of which is, to effect the mixture of the air with the gases in the region where the temperature ought to be brought to its maximum.

The air is admitted by a register in the door, the steam, by a tube T, placed above it in the fire-box, and into which the steam is directed as desired by means of a tube 0, coming from the boiler, and entering and

ending the inside θ, tube, and provided with a cock R, under the driver's hand. The tube T, closed at the two ends, is pierced (*fig.* 11) with a certain number of holes, at a suitable distance apart, from each other, and suitably directed. Their space, their diameter and their direction are determined by the condition, that the steam-jets formed by their expansion, form a sort of continued sheet, extending as far as the edge of the layer of fuel, dividing in some sort, the fire-box into two compartments throwing down the air, admitted into the lower compartment, and thus producing, in a more complete manner, and without involving the same disadvantages, the effects of M. *Friedmann's* hood.

The tube is of iron, 1,80 inch external diameter, and 0,98 inch inside; it is protected against the flame by a shield *b* (*fig.* 8); the holes, six or eight in number, are from 0,079 to 0,098 in diameter, their arrangement, evidently symmetrical relatively to the mean vertical plane of the boiler, and their number, depend, besides, on the dimensions of the fire-box, and of the nature of the fuel. Previous trials are thus necessary.

During standing, the *Thierry* tube never acts alone; as soon as the regulator is closed, the blower (106), which at the same time is often sufficient, is always open, in order to re-establish the draught, and frequently the fire-door as well.

Like the blower, the steam injection tube also serves to hasten getting up steam; their simultaneous action as soon as the pressur reaches 3 atmospheres, allows the pressure thereafter to be very rapidly raised.

"Experience has proved," says the driver's Regulation Book of the Eastern of France (art. 287), "that these smoke-consuming apparatus can act without the engine pro-"ducing smoke, and without increasing the expenditure of fuel. In consequence, drivers "of engines provided with smoke-consuming apparatus are injoined to avoid all pro-"duction of smoke as well while standing as during running."

The statement that these apparatus are without influence on the consumption, can only be taken as quite exact, by making abstraction of lengthened stoppages.

The Eastern of France did not arrive at getting any good out of *Thierry's* apparatus without difficulty, although they have been trying it since the year 1864. It was objected to, not only because it imperfectly attains its object, suppression of the smoke, but, also, because it interferes with the draught, and requires a stronger blast; which was attributed to the fact that the descending steam jets cut across the ascending current of the gases and stop its passage. The inclined sheet of air in *Tenbrinck's* apparatus, produces

the same effect. Besides even should this more or less contrary conflict of currents have a certain influence on the mechanical conditions of the draught (which is in no way established), it should not the less be accepted, for it is the only means of obtaining the mixture of the gases and of the air, a mixture which is the principal condition of complete combustion, and in fine, of economy.

Some modifications in the details, together with the experience acquired by the drivers, have ended by overcoming the difficulties of application: difficulties by which one must never be too soon discouraged. *Thierry's* apparatus is sufficiently smoke-consuming with the *Saarbrücke* coal, which is however very smoky. It is also simply set up and kept in order.

It gives also good results on the *Mediterranée* system, particularly with block-fuel, which is very much used on those lines.

All the passenger engines are provided with the *Thierry* apparatus, and with a blower; all the goods-engines with the blower only. The same thing is done on the Southern Austria lines.

"By the aid of these apparatus", says one of the instructions (114 art. 7) of the locomotive department of the first, "the drivers of the passenger service can completely "consume the smoke of their engine, while running or during stoppages, and the dri- "vers of goods trains may almost completely consume the smoke of their engines at the "stations, during stoppages, and standing. *Numerous and conclusive experiments* "*leave no doubt with regard to this.*"

"However, it is often ascertained that engines of passenger trains smoke, principally "during running but also during stoppages, and that the engines of goods trains fill the "stations with smoke during the stoppages. This state of things, due to the negligence "of the drivers, has on several occasions provoked observations from the Railway De- "partment, and complaints from passengers, or from the localities passed through. It "is desirable that a stop should be placed to this."

After this preamble naturally come the penalties.

These recommendations, which date back to 1868, are reproduced from time to time, which proves that in spite of the penalties, they are not attended by complete success.

Truly speaking, the evil does not appear very great to us in France, especially if we judge by comparison with what takes place on a great number of foreign railways, where the engines smoke unheeded. There remains however, even with us, something to be done. One of the obstacles is the repugnance which is experienced by station-masters against addressing the drivers, as their observations may be sometimes badly received. Drivers

are rather touchy as to the technical part of their functions, and little disposed to accept in such a matter, what they regard as an interference on the part of officials under whose orders they do not happen to be. Station-masters know it, and they shut their eyes, so as to avoid anything disagreeable; the traffic department should check a weakness which in this case amounts to a sort of complicity.

Of all the French systems, the *Orleans* has to deal with the most objectionable coals, with respect to smoke. Excepting on the Brittany line, which is supplied from Wales, it consumes the very smoky coals of *Aubin*, *Decazville*, *Bezenet*, *Ahun*, etc. Prolonged trials have led to the conclusion that the *Tenbrinck* apparatus (Pl. III, *fig.* 1 to 4) and that of *Bonnet* (*fig.* 5 to 8) are alone, the first particularly, completely smoke-consuming. Thus, the first is at work, nowadays, on all the passenger engines. The suppression of the smoke is not, in spite of its importance, the sole motive for this measure; the *Tenbrinck* apparatus, by its arrangements as a whole, and particularly by the inclination of the grate (which at the same time is in no way special to it) facilitates greatly the of coal which would be scarcely manageable in ordinary fire-boxes.

It is however applied only on the *Orleans* lines to large coal, or at least nearer large than unscreened. On this system they had not to take up the question of the use of coal dust. That which is produced in the collieries which supply it, finds of course a use in the manufacture of coke for smelting furnaces.

The essential characters of the *Tenbrinck* box are :

1st. The nearly continuons charging of the fuel brought to the suitable state of division, and without opening the door. This *quasi*-continuousness of charging the fire, by avoiding abrupt changes, is in itself an efficaccous means of avoiding, or rather of distributing the smoke.

2nd. The more or less rapid progression of the coal on the inclined grate, as the distillation is effected;

3rd. The introduction of air above the fuel, in variable quantity as desired, and in the form of an inclined sheet;

4th. The addition, in the fire-box of a waterspace, or mid feather (B) forcing the air and the products of distillation to mix together, and to run along a tortuous circuit before passing into the tubes.

The fire-door, which, when it remains, only serves for examining the tubes, and the cleaning out of the ferrules by the brush, is replaced with advantage by two side openings *r*, *r* (*fig.* 1, and 2). Above the door, or above these openings, a rectangular opening *m n p q* (*fig.* 2) is made in the

two hind plates, occupying the whole width of the inside box, and divided into two compartments, the lower one for charging the fire, the other for the introduction of the air. The first receives a projecting case T (*fig.* 1 and 4), see also (II, Pl. XXXV; Pl. XXXVII; Pl. XLVIII, *fig.* 8) provided with a flap valve *k*, and the bottom of which inclined to the horizon at an angle of from 35° to 40° forms the continuation of the grate, composed of two parts : the one fixed G, the other horizontal and movable balanced and able wing by means of the handle M, either completely, so as to throw down the fire, or partially when required to let the clinkers fall out.

In principle the inclination varies according to the nature of the coal, which ought to run down of itself; the angle of 35°, for example, was found on the Eastern of France, to be the best suited for the *Saarbrücke* coal, which is poor, very smoky, and the unscreened of which contain from 15 to 20 per cent of dust. M. *Tenbrinck* has taken advantage of the inclination of the fixed grate to give the driver the means of poking the fire during running, when the space between the bars is large enough to allow poking. An opening arranged in the foot plate, immediately below the case and closed by a flap, allows the driver to see below the fixed grate and get at all its parts with the pick;

5th. The air pallet π (*fig.* 1), regulating its admission in the form of a sheet rubbing along the inclined top of the fuel, and encountering the products of distillation at the moment of their emission.

The part of the water-space B, which besides, more than restores, to the direct heating surface that which bas been taken therefrom by the lower cut into the fire-box, is all important. The flame produced by the coal on the lower grate is forced to rise, licking and heating that which covers the inside grate. Mixed with the gas, and the vapors disengaged by the coal thus heated this current comes against the descending current of air introduced by the pallet, which it drives back, and mixes with, and the whole after having whirled about is deflected anew in order to pass through the strangled space B, comprised between the water-space, and the hind plate of the fire-box, and directs itself towards the upper surface of the tubes along the upper surface of the water-space.

The void which exists at the lower edge of the water-space has to be stopped up, otherwise a part of the current would take that, being the shortest way. It is intercepted by pieces of fire brick, *v* (*fig.* 1).

On account of their small section and of their relatively low temperature (that of the steam) the tubes lower that of the cylinder of gas which passes through them. Their function is in effect to cool the gases but they are detri-

mental to the combustion already too imperfect and by the very fact of the cooling, and the parallelism which they impart to the gaseous currents, and which excludes their ultimate mixture in the tubes. It is of importance to avoid as much as possible an excess of air in certain tubes, and a want of air in others; a very intimate previous mixture of the gases is thus an essential condition of their complete combustion. The water-space appears to fulfil in this respect, and independently of the special object of the consumption of the smoke, a function which deserves to be studied more closely.

Introduced only with the view of increasing the direct heating surface, the water spaces previously tried (15) presented serious disadvantages : by their position, they rendered combustion very difficult, and interfered with stoking; further, the mode in which they were joined to the sides of the fire-box, from the want of freedom to expand and contract, developed considerable tensions in the whole system, which soon terminated in cracks. Regarded only also as a supplement to the heating surface, M. *Tenbrinck's* waterspace, without sacrificing any of the evaporating power, and without coming in front of the tubes so far as to become inconvenient (excepting for plugging) (24), escapes in a great measure by its position, the objections raised to the others; and on the other hand, its connection with the sides of the fire-box not being made by angle-irons riveted, but by four tubes 0, 0, two of which are very long, possesses sufficient flexibility to counteract the injurious effects of changes of temperature.

Washing-out plugs *l l* (*fig.* 4) facilitate the direct cleaning of these tubes.

In some ordinary fire-boxes also, a water space is to be found, placed like that of *Tenbrinck's*; for example in the Great Northern American bogie engine (II Pl. LXXV, *fig.* 4, B), but without the elasticity of the joints, which is however indispensable. The smoke-consuming, or rather preventing action of the water-space is at the same time taken advantage of, in which action the air admitted by a register in the door, and thrown down by the small deflector *a*, cooperates.

The trials to which I subjected the greater part of the coals employed on French Railways (*), as far back as 1862, proved that the *Tenbrinck* apparatus allows smokeless running with almost all of them. There was nothing surprising in the success being less, and the difficulties greater with some (*Epinac*, *Ronchamp*, etc.). Each description of coal requires a special mode

(*) Report to the Minister of Public Works on the use of coal in locomotive engines, etc. (*Annales des Mines*, 6th series, vol. I, 1862, p. 1.)

of stoking, a knack which the fireman does not catch hold of at once. At the present day, after the results obtained by long practice on the *Orleans* lines, all doubt has disappeared, and it may be asserted that *Tenbrinck's* apparatus is at the same time thoroughy smoke-consuming, and quite practical.

Should the descent of the coal be checked by any cause, it is sufficient to lift the flap T, and to stir the mass with the bar. As to the working of the air pallet (which still admits a little at the end of its travel), the driver is guided by very clear indications. If it is not sufficiently open, the engine smokes, because there is not enough air for the direct consumption of the products of distillation. If it is too open, the engine still smokes; this time, on account of the cooling due to the great excess of air. The happy medium is thus easy to obtain. Experiment proves, in fact, that in the hands of a good driver, the *Tenbrinck* box is, also, economical.

The apparatus is suitable even for the combustion of unscreened coal, provided the proportion of dust be not excessive. It is not applicable to very large and shallow fire-boxes, with the grate horizontal, or very little inclined, of the *Belpaire* type. But this type is simply made for burning small coal, and is applicable especially to powerful goods engines, in which the complete suppression of the smoke during running, is only of secondary importance.

M. *Bonnet* (*) has introduced on the Eastern of France an arrangement which, while keeping the essential characteristics of *Tenbrinck's* box, and without pretending to replace it by anything new, simplifies the application. This variation has been made in two forms: one is represented by *figs* 5 to 8, Plate III, as it is applied on the *Orleans* lines, that is to say with the air in-take simply made by a register in the door, and a small deflector a; in the other, which it is unnecessary to describe in detail, the air in-take is effected by a horizontal rectangular orifice, taken on the grate itself, behind, and provided with a flap; an arrangement which has the drawback of reducing both the grate surface and the heating surface, and the advantage of introducing into the fire-box air already heated by its contact with a vertical cast-iron partition, which only resists, by the way, because one of its surfaces is constantly cooled by the air.

Charging the fire, which is done intermittently, is effected as ordinarily, through the door, at the top of the inclined grate. It is there that the

(*) Note on the smoke consuming fire-box on *Tenbrinck's* system, modified by M. *Bonnet*. (*Annales des mines*, 6th series, vol. II, 1862, p. 343.)

distillation takes place, the products of which ought to commence to mingle with the air, before the coal goes down the grate by its weight, the action of which is assisted by the jolting of the engine. At the moment of charging, the driver opens the register (*figs* 6 and 7) of the door, shuts it gradually, until the smoke commences to appear, and opens it again a little.

Less complete, less thorough than that of M. *Tenbrinck*, M. *Bonnet's* apparatus escapes from a drawback of a certain importance, which the first presents in summer. On ordinary engines, the driver is separated from the fire-box by a sheet of water only interrupted by the door, which is of small dimensions. On engines having *Tenbrinck's* fire-box, the high temperature of the large hopper is often annoying, and can only be kept down by frequently watering the foot-plate.

As to the expense of setting up, *Bonnet's* apparatus has naturally the advantage; it leaves the fire-box intact, and allows other arrangements to be applied, or the old one to be returned to, with the horizontal grate.

The grate of *Tenbrinck's* and *Bonnet's* boxes on the *Orleans* lines presents a peculiarity: the bars are arranged, not parallel to each other but like a fan, (*figs*. 3 and 8 G, G) and consequently decrease in length towards the sides. The width of the air-passage increases thus from the back of the grate to the front, in proportion to the tendency to obstruct the grate towards the bottom; that is to say, the nature of the coal consumed by these engines, and which might otherwise not be suitable, and even be detrimental.

The question of smoke has not occupied much attention in Germany. The apparatus most used, that of M. *Stössger*, which dates back to 1861, consists of a cast iron cylinder, 8.6 to 10.9 inches in diameter, and 14.8 to 16.8 inches in height, let in vertically at the middle of the grate, on a ring at which the bars end. The air introduced by this tube is deflected downwards by a hood which surmounts it, forming a sheet, which mingles with the products of distillation. Although cooled by the air which passes through it, the cylinder is rapidly destroyed. It is also objected to, as hastening the destruction of the sides of the fire-box, at the level of the sheet of air it has also the disadvantage of reducing the surface of the grate.

§ VIII. — Various combustibles burnt in locomotives.

107. Locomotives burn not only all varieties of mineral fuel, from anthracite to lignite, but also turf and wood. The latter is indeed the fuel of all others; none at least saves the fire-box and the tubes so well. But, in Europe, its use is only local and temporary; so rapidly does a railway of great traffic clear away the forests which supply it. Turf, very good also from the point of view of the preservation of the fire-boxes, labours under inherent disadvantages of the lowness of its specific weight and calorific power. In general, for 1 of coal, 2 in weight and from 8 to 10 in bulk, of *ordinary* turf (not prepared) are required. The tender is then insufficient; and the supply must be completed by an auxiliary vehicle; a special man for charging being required, or two firemen instead of one, for powerful engines; the fire has to be charged almost incessantly, and consequently the door always kept open (unless M. *Prüssman's* apparatus be employed, which is a sort of chamber with two doors attached together in such a way that when one is open the other is shut). Lastly, immense sheds with large screens are necessary, for drying and storing the turf. The traction is thus burdened with a very considerable extra expense. Thus a decided tendency is remarked, even in the countries best situated with regard to the abundance and the quality of the turf, to restrict its use. In Bavaria, for example, coal supplants turf more and more, and if it has not yet encroached upon the natural domain of the latter, it keeps the turf confined to it. It is even probable that the Railway Department would have gone farther in the way of restriction, had it not been restrained by the gravity of a measure affecting one of the rare branches of industry with which districts that supply turf are endowed.

The preparation of turf by grinding, divides its filaments, purifies it, and produces a homogeneous mixture; moulding, and above all, compression ought to have improved the conditions of the use of this fuel in locomotives. Many trials were made in *Hanover*, in *Bavaria*, and in *Wurtemberg;* the mechanical preparation was indeed regularly at work as far back as 1849 in the vast marshes of *Haspelmoos*, between *Munich* and *Augsburg*; and later, in 1857, turf reduced to powder, dried at a high temperature, and compressed in cylinders while hot, gave a dark brown, dense fuel, hard enough to take a very decided polish. But whatever may be the advantages of the increase of specific weight, they do not seem to warrant

expensive preparation, and the use of turf in the natura state has generally prevailed.

Turf carbonized has also been tried, particularly on some Swiss lines, where it bore the name of *Lara* coal. It was a perfect fuel, the best of all, according to the engineers who employed it; but was too dear to stand against coal.

Turf is a fuel which most assuredly cannot be despised, while it possesses the precious quality of insuring the fire-boxes and the tubes a mileage three times as great as with coal. Its use seems to be, definitively, the more advantageous, all complications and previous preparation being dispensed with; but as it is necessarily restricted to some particular cases, there is no occasion for dwelling longer on this point.

Mineral oils, coal-tar, etc. are certainly excellent fuels, easy to burn completely, without a great excess of air, and without smoke, but the obstacle to their use, is their high price, which most certainly shows no sign of any reduction at present. There is no interest in bringing forward a question which will probably never arise, and it is useless to take up time with the trials which were made some years ago on the Eastern of France, and more recently in Australia.

108. To conclude, let us borrow, for example, some useful information from service order No. 4 of the locomotive department of the Eastern of France : the weight of the cubic foot of the different fuels in use on that system :

		lbs.
Prussian coal, large, well rammed		1,808
do	old heaps	1,786
do	unscreened	1,830
Square blocks,	well rammed	2,425
Round do	large radius	2,205
do do	small radius	2,139
do do	thrown all in a heap	1,698 to 1,764
Prussian coke		904 » 926
Belgian do		1,102
Aubervilliers, do	(Gas Company)	970 to 992

The same regulation prohibits « keeping fuel beyond from 6 to 8 months. « The fuel stored in the course of the summer, ought to be consumed in « the course of the following winter, latest after. »

§ IX. — Steam In-take. — Regulator.

109. The in-take of the steam and the regulator may be combined, or separate. In principle, there is some advantage in placing the second as near as possible to the steam-chest, in order to reduce the volume of steam contained in the induction tube, which, when the regulator is closed, constitutes a sort of void space. It is thus, that in *Stephenson's newly patented* type of engine, with inside cylinders and domed fire-box crown, the opening of the steam pipe was placed in this crown, and the regulator at the other extremity of this pipe, outside the boiler, immediately above the steam chest, common to the two valves. But this arrangement, very suitable for engines with inside cylinders, would be, if not impracticable, at least very complicated, with outside cylinders, as in that case there are then two valve-boxes, and each of them would require its own regulator. At present, as we have seen (38), boilers have almost always a dome, and the steam intake goes up vertically thereinto; it, as is most often the case, the regulator is applied on the very opening of this pipe, the latter curves back like a swan's neck, and receives the movable organ, which is in this case a slide pressed by springs against a plate pierced with openings like the slide itself. With the regulator placed thus at its origin, the induction pipe is subjected for its whole length to the pressure of the steam, when the regulator is closed. It must thus not be made too thin; a thickness of from 0,20 to 0,24 inch is sufficient for a diameter of 5 inches, and existing high pressures.

Examples of this regulator are found in these engines: *Sigl's* (II, Pl. XXV, *r*, *r*); Mediterranean altered, (Pl. XXVIII); *Orleans* mixed (Pl. XXXV); Western of France, six wheels coupled; (Pl. XLI and XLIII); tank-engine of the same line (Pl. XLIV); *Orleans* eight wheel coupled, (Pl. XLVIII); ditto Northern of Spain (Pl. L.); ditto *Moscow* to *Kursk* (Pl. LIII); *Orleans* ten-wheeled; (Pl. LXVIII); *Engerth* (Pl. LXXVI) etc.

With the great dimensions and high pressures of existing engines, the working of the regulator is often a little hard. Now it is necessary that the driver should open this organ gradually, and without having to exert in doing so any considerable effort, difficult to measure, as such would often open the regulator too much; and the regulator opened abruptly, often causes the couplings to break. This drawback is avoided (Pl. IV, *fig.* 22), by applying to the principal regulator, a small slide, which, worked first,

and easily, on account of its small surface, uncovers the opening in question; the large slide is thus set free (*déplaqué*) by the equilibrium of the pressures, and in its turn is easily worked, by the continuation of the movement of the same lever. When the regulator r is shut, the auxiliary slide, r', the full surface and friction of which are consequently very small, covers, by a full space, the small opening o of the first; when the forked rod B lowers, it takes with it at first r' only, the bolt a fixed without play at r', sliding in the slot g made in r, which remains immovable until the pin a comes up against the bottom $m\ n$ of the slot. Then r' has uncovered the opening o, the desired effect is produced, and the two slides are moved together as one.

The auxiliary slide r' acts evidently for opening only, and not for closing. But the precision and measure required by the first operation, are not necessary for the second.

This addition, which has long been in use on the *Orleans* lines, and on others, (example: *Vaessen* engine II Pl. LXVI, r, r') in no way complicates the mechanism. This is not so if, as has sometimes been done, each of the slides is worked by a special crank and rod: the crank of the auxiliary slide being keyed at 90° to the other, and consequently horizontal, when that of the regulator, closed and at the end of its travel, is vertical. This is a gratuitous complication.

The slide is often placed horizontally, either in the steam dome, or in a special box, applied on to the boiler towards the front, and divided by the face on which the valve slides, into two compartments; in communication, the one with the in-take pipe, the other with the two pipes leading the steam into the cylinders. The mixed high speed engine of the Northern of France, (II Pl. XXX and XXXII, *fig.* 2) presents the last arrangement. In the dome, the intake-pipe is terminated by a branch; that is to say, it is ramified into several small pipes, p, p, p, which go up almost to the very top of the dome, so that the steam is forced to change its direction abruptly in order to rush in through their openings. The regulators of the six-wheeled coupled engines of the Southern (II Pl. XXXIX) and that of the eight-wheeled coupled engine of the Ceinture (*Kœchlin*) (II Pl. LV and LVI) are similar to the preceding one.

In other cases, the regulator, always with a slide, and horizontal, is placed in a box forming the widening out of the vertical in-take pipe (mixed engine of the Western of France, II. Pl. XXXIX; *Fairlie* engine, Pl. LXXIII).

In *Crampton's* engines the box communicates directly by an opening made in each of its sides with the two exterior pipes ending in the cylinders. The

regulator is thus double, and the rod which works it, acts by a simple movement of translation on two slides applied by springs to the sides of the box. The openings made in these latter, are terminated at the front by a chevron (Pl. IV *fig* 23) which allows the driver to send only a thread of steam into the cylinders. There is no dome, and the intake pipe hung in the boiler, (38) receives the steam which enters it, through a series of openings parallel to the axis, the part of which is probably very secondary.

110. *Balanced regulators*. Although the slide regulator, easy to work and to maintain, is generally adopted, other organs are sometimes preferred to it; for example, a valve, a form which is very well adapted for complete equilibration. Figs 24 to 26 Pl. IV represent the equilibrated regulator, applied to the engines of the little *Commentry* line, and can be understood at a glance. The rod of the valve S carries a metallic piston P, movable in a bored out appendage M M of the intake pipe, so that the difference of the contrary pressures exerted upon S and P, when the first is applied to its seat, may be reduced as much as desired. The sensibility of the apparatus is regulated by means of the counterpoise Q, which lends to open the regulator.

An almost identical apparatus, is at work on the line from *Berlin* to *Hamburg*. According to the « Hand-book of Railway Work » (*), this regulator, known in Germany under the name of *Clapet's*, was the object of continued trials on the State railways in Prussia, made in accordance with a ministerial order. It acts well, as long as every thing is in order; but with impure water, the valve and the piston soon cease to be tight. On the other hand, this apparatus is less adapted than the slide, for sending in small quantities of steam. The same conclusion has been arrived at, with regard to another equilibrated regulator founded on the same principle, M. *Grimmer's*, which we refrain from describing, on account of the doubts expressed as to its value by the engineers who have made use of it.

The *Cornwall* valve can evidently be employed, and has been used by Mr. *Ramsbottom*, and long before him by *Jackson*. But a slight inequality in the expansions is sufficient to prevent the narrow conical bearing of the valve from going down simultaneously on to its seat, and leaks follow from this. Elsewhere, a rotating organ has been adopted : this is sometimes,

(*) *Handbuch für specielle Eisenbahn-Technik*, vol. III, p. 420. — *W. Engelmann, Leipzig*, 1874.

Engine 852. — *Gooch's* motion.

TABLE I. No. 208.

DEGREE OF EXPANSION	FORWARD GEAR 10	9	8	7	6	5	4	3	2	1		BACKWARD GEAR 1	2	3	4	5	6	7	8	9	10
Lead (inches)	stroke direct-back. 0,22 0,24	stroke direct-back. 0,22 0,24	stroke direct-back. 0,22 0,24	stroke direct-back. 0,22 0,24	stroke direct-back. 0,22 0,24	stroke direct-back. 0,22 0,24	stroke direct-back. 0,22 0,24	stroke direct-back. 0,22 0,24	stroke direct-back. 0,22 0,24	stroke direct-bakc. 0,22 0,24	Dead	stroke direct-back. 0,22 0,24	stroke direct-back. 0,22 0,24	stroke direct-back. 0,22 0,24	stroke direct-back. 0,22 0,24	stroke direct-back. 0,22 0,24	stroke direct-back 0,22 0,24	stroke direct-back. 0,22 0,24	stroke direct-back. 0,22 0,24	stroke direct-back. 0,22 0,24	stroke direct back. 0,22 0,24
Max. opening of port (inches)	1,30 1,02	1,10 0,87	0,94 0,76	0,76 0,63	0,65 0,53	0,51 0,45	0,42 0,39	0,37 0,31	0,30 0,27	0,24 0,24		0,25 0,25	0,32 0,35	0,35 0,33	0,45 0,41	0,57 0,51	0,69 0,61	0,85 0,73	0,94 0,83	1,08 0,96	1,23 1,08
— Mean do	1,16	0,98	0,85	0,70	0,59	0,59	0,41	0,32	0,28	0,24		0,25	0,30	0,35	0,43	0,54	0,65	0,79	0,89	1,02	1,14
Admission (per cent of stroke)	61 1/2 70	63 65 1/2	59 1/2 61	53 54	47 47 1/4	40 40	33 34	24 24 1/2	17 1/2 18	11 1/2 12 3/4		13 13 1/4	19 1/1 20	26 1/2 27	35 36	42 1/2 44 /2	49 51	56 58 1/2	60 63 1/2	64 68 1/3	
Mean do. do	68 1/2	64 1/2	60 1/4	53 1/2	47 1/4	40	33 1/2	24 1/4	17 3/4	12		13 1/4	19 3/4	26 3/4	35 1/2	43 1/2	50	57 1]4	61 3/4	66 1/4	
Exhaust do	12 1/2 9	14 10 1/2	14 10 1/2	18 1/2 15	21 17 1/1	25 21	28 1/2 24 1/2	32 1/2 30	28 1/2 35	44 41		43 40	36 1/2 33	31 27 1/2	26 1/2 22 1/2	22 1/2 18 1/2	19 1/2 15 1/2	16 13	14 11	12 9 1/3	
Mean do. do	10 3/4	12 1/4	12 1/4	16 3/4	19 1/4	23	26 1/2	31 3/4	31 3/4	42 1/2		41 1/2	34 3/4	23 1/4	24 1/2	20 1/2	17 1/2	14 1/2	12 1/3	10 3/4	
Compression do	9 1/3 13	11 14 1/2	11 14 1/2	15 1/2 19	18 21 1/2	21 1/2 25 1/2	25 29	30 1/2 34	36 39 3/4	42 45		41 44	34 37 2/2	28 1/2 32	28 27	19 23	16 20	13 1/2 16 1/2	11 1/3 14 1/2	10 12 1/3	
Mean do. do	11 1/4	12 3/4	12 3/4	17 1/4	19 3/4	23 1/2	27	32 1/4	37 3/4	43 1/2		42 1/2	35 3/4	30 1/4.	27 1/2	21	18	15	13	11 3/4	
Travel of slide (inches)	inches. 4,68	inches. 4,33	inches. 4,08	inches. 3,75	inches. 3,54	inches. 3,32	inches. 3,19	inches. 3,02	inches. 2,92	inches. 2,84		inches. 2,86	inches. 2,96	inches. 3.06	inches. 3,23	inches. 3,45	inches. 3,76	inches. 3,94	inches. 4,41	inches. 4,72	
Disturbance do	0,74	0,63	0,51	0,35	0,30	0,26	0,20	0,14	0,08	0,06		0,04	0,06	3,08	0,12	0,16	0,24	0,28	0,28	0,34	

Séries 1 to 32. — *Gooch's* motion.

Cylinders	15.7 × 23.6 inches	Ports	1.38 inches
Laps outside	1.18 do.	Maximum travel	4.72 do.
Laps inside	0.02 do.	Angular advance	30° and 30°

TABLE II.

D.	FORWARD GEAR 10	9	8	7	6	5	4	3	2	1		BACKWARD GEAR 1	2	3	4	5	6	7
Lead (inches)	stroke direct-back. 0,18 0,20	stroke direct-back. 0,18 0,20	stroke direct-back. 0,18 0.20	stroke direct-back. 0,18 0,20	stroke direct-back. 0,18 0,20	stroke direct-back. 0,18 0,20	stroke direct-back. 0,18 0,20	roke -back. 0,20	stroke direct-back. 0,18 0,20	stroke direct-back. 0,18 0,20		stroke direct-back. 0,18 0.20	stroke direct-back. 0,18 0,20	stroke direct-back. 0,18 0,20	stroke direct-back. 0,18 0,20	stroke direct-back. 0,18 0,20	stroke direct-back. 0,18 0,20	stroke direct-back. 0,18 0,20
Max. opening of port (inches)	1,22 1,06	1,06 91	0,91 0,74	0,70 0,14	0,56 0,51	0,39 0,39	0,35 0.35	,32	0,24 0,28	0,20 0,24		0,20 0,28	0,28 0,35	0,39 0,43	0,55 0,55	0,74 0,74	1,02 0,90	1,22 1,10
— Mean do	1,14	0,98	0,82	0,65	0,53	0,39	0,35		0,26	0,22		0,24	0,31	0,41	0,55	74	0,96	1,16
Admission	72 74	66 68	62 65	56 58	47 49	38 40	32 33	26 28	21 23	16 18		17 20	24 28	36 41	4[51	57 61	64 68	70 74
Mean do	73	63 1/2	63 1/2	57	48	39	32 1/2	27	22	17		18 1/2	26	38 1/2	49	59	66	72
Exhaust	9 8	12 10	14 11	16 13	20 16	24 20	27 23	31 26	35 30	39 34		39 33	33 28	25 20	21 16	17 12	14 9	12 7
Mean do	8 1/2	11	12 1/2	14 1/2	18	22	25	28 1/2	32 1/1	36 1/2		36	30 1/2	22 1/2	18 1/2	14 1/2	11 1/2	9 1/2
Compression	8 9	10 12	11 14	13 16	16 20	20 24	23 27	26 31	30 35	34 39		33 39	28 33	20 25	16 21	12 17	9 14	7 12
Mean do	8 1/2	12	12 1/2	14 1/2	18	22	25	28 1/2	32 1/2	36 1/2		36	30 1/1	22 1/2	18 1/2	14 1/2	11 1/2	9 1/2
Travel of slide (inches)	inches. 4,66	inches. 4,28	inches. 4,02	inches. 3,70	inches. 3,43	inches. 3,19	inches. 3,07	inches. 2,96	inches. 2,83	inches. 2,76		inches. 2,83	inches. 3,00	inches. 3,23	inches. 3,47	inches. 3,86	inches. 4,24	inches. 4,66
Disturbance	0,47	0,43	0,39	0,35	0,31	0,28	0,24	0,20	0,16	0,12		0,12	0,24	0,32	0 47	0,55	0,69	0,79

Engines 988 to 994 (6 coupled wheels). *Stephenson;* direct rods. Link hung by the centre.

Cylinders . . . . . 15.95 × 23.82 inches | Laps { outside . . . . . 1.18 inches
Total travel of slide . . . . . 4.96 do. | { inside . . . . . 0.02 do. | Angular advance, 28° and 28°.

TABLE III. No 208.

	FORWARD GEAR											BACKWARD GEAR									
DEGREE OF EXPANSION	10	9	8	7	6	5	4	3	2	1		1	2	3	4	5	6	7	8	9	10
Lead and Retard (R)	stroke direct-back. R 0,4 R 0,12	stroke direct-back. R 0,2 R 0,8	stroke direct-back. 0 R,04	stroke direct-back. 0,08 0	stroke direct-back. 0,14	stroke direct-back. 0,16 0,12	stroke direct-back. 0,16 0,12	stroke direct-back. 0,18 0,14	stroke direct-back. 0,18 0,10	stroke direct-back. 0,18 0,16	Dead	stroke direct-back. 0,20 0,16	stroke direct-back. 0,16 0,12	stroke direct-back. 0,16 0,10	stroke direct-back. 0,12 0,8	stroke direct-back. 0,12 0,04	stroke direct-beak. 0,08 0	stroke direct-back. 0,8 R 0,04	stroke direct-back. 0,02 R 0 1/2	stroke direct-back. R 0,02 R0,20	str oke direct-back. R0,02 R0,20
Max. opening of ports	1,48 1,10	1,30 0,98	1,10 0,86	0,94 0,70	0,79 0,60	0,47 0,39	0,47 0,39	0,35 0,31	0,28 0,24	0,24 0,20		0,28 0,16	0,32 0,20	0,39 0,28	0,51 0,35	0,67 0,47	0,79 0,60	0,94 0,70	1,10 0,86	1,26 0,98	1,44 0,90
.....	1,30	1,14	0,98	0,86	0,69	0,57	0,43	0,34	0,26	0,22		0,22	0,26	0,34	0,43	0,57	0,59	0,82	0,98	1,12	1,30
.....	79 82	75 78	71 74	66 69	60 62	51 54	43 45	32 34	21 24	14 16	Point	17 14	24 21	33 30	43 42	52 52	59 60	66 70	70 74	76 78	80 82
.....	80 1/2	76 1/2	72 1/1	67 1/2	61	52 1/2	44	34	22 1/2	15		15 1/2	22 1/6	31 1/2	42 1/2	52	59 1/2	68	72	77	81
.....	6 5	7 6	9 7	10 9	13 11	17 14	20 18	25 23	32 28	40 36		40 38	33 30	26 23	21 17	16 14	13 11	10 9	7 7	6 6	5 5
.....	5 1/2	6 1/2	8	9 1/2	12	15 1/2	19	24	30	38		39	31 1/2	24 1/2	19	15	12	9 1/2	7	6	5
Compression	5 6	6 7	7 9	9 10	11 13	14 17	18 20	23 25	28 32	36 40		38 40	30 33	23 26	17 21	14 16	11 13	9 10	7 7	6 6	5 5
Mean do.	5 1/2	6 1/2	8	9 1/2	12	15 1/2	19	24	30	38		39	31 1/2	24 1/2	19	15	12	9 1/2	7	6	5
Travel of slide (inches)	inches. 4,92	inches. 4,64	inches. 4,29	inches. 4,02	inches. 3,70	inches. 3,27	inches. 3,23	inches. 3,07	inches. 2,88	inches. 2,80		inches. 2,80	inches. 2,92	inches. 3,07	inches. 3,31	inches. 3,47	inches. 3,74	inches. 3,98	inches. 4,53	inches. 4,64	inches. 4,96
Disturbance	0,70	0,64	0,55	0,47	0,39	0,39	0,39	0,35	0,35	0,35		0,20	0,20	0,24	0,24	0,24	0,32	0,39	0,47	0,64	0,70

Engines 983 to 987 (6 coupled wheels). *Stephenson;* direct rods.

Cylinders . . . 15.95 × 23.82 inches. | Total travel of slide . . . 4.96 inches. | Angular advance . . . 11° and 11°.

TABLE IV.

	FORWARD GEAR											BACKWARD GEAR								
DEGREE OF EXPANSION	10	9	8	7	6	5	4	3	2	1		1	2	3	4	5	6	7	8	9
Lead or Retard (R)	stroke direct-back. R 0,16 0	stroke direct-back. R 0,16 0,04	stroke direct-back. R 0,12 0,08	stroke direct-back. R 0,08 0,12	stroke direct-back. R 0,08 0,12	stroke direct-back. R 0,04 0,16	stroke direct-back. R 0,04 0,18	stroke direct-back. 0 0,20	stroke direct-back. 0 0,24	stroke direct-back. 0 0,24	Dead	stroke direct-back. 0 0,24	stroke direct-back. 0 0,22	stroke direct-back. 0 0,20	stroke direct-back. R 0,04 0,24	stroke direct-back. R 0,08 0,16	stroke direct-back. R 0,08 0,16	stroke direct-back. R 0,12 0,06	stroke direct-back. R 0,14 0,04	stroke direct-back. R 0,16 0
Max. opening of ports	1,02 0,94	0,94 0,86	0,82 0,74	0,70 0,68	0,64 0,56	0,48 0,48	0,35 0,39	0,24 0,32	0,16 0,28	0,10 0,26		0,08 0,28	0,16 0,36	0,24 0,39	0,39 0,47	0,47 0,55	0,60 0,68	0,79 0,79	0,90 0,90	1,02 1,98
Mean do.	0,98	0,90	0,78	0,69	0,60	0,48	0,37	0,28	0,22	0,18		0,18	0,26	0,32	0,43	0,51	0,64	0,79	0,90	1,00
Admission	72 84	71 81	68 76	64 70	60 64	54 56	47 45	38 36	20 28	19 21	Point	15 23	23 29	33 38	44 48	52 57	58 63	65 71	70 76	74 78
Mean do.	78	76	72	67	62	55	46	37	29	20		19	26	35 1/2	46	54 1/2	60 1/2	68	73	76
Exhaust.	6 3	7 3	8 4	8 4	11 9	14 9	18 21	21 17	25 21	28 26		32 32	28 24	22 18	17 11	14 8	12 7	9 5	7 4	6 3
Mean do.	4 1/12	5	6	6	10	11 1/2	19 1/2	19	23	27		32	26	20	14	11	9 1/2	7	5 1/2	4 1/2
Compression	5 11	6 12	7 13	7 13	12 18	15 21	20 26	26 30	31 35	33 39		42 44	36 38	28 32	20 26	15 21	12 18	10 15	8	6 10
Mean do.	8	9	10	10	16	18	23	28	33	36		43	37	30	23	18	15	12 1/2	12 10	8
Travel of slide (inches)	inches. 3,86	inches. 3,78	inches. 3,35	inches. 3,35	inches. 3,10	inches. 2,91	inches. 2,68	inches. 2,52	inches. 2,44	inches. 0,22		inches. 2,36	inches. 2,44	inches. 2,60	inches. 2,84	inches. 2,98	inches. 3,19	inches. 3,50	inches. 3,74	inches. 3,94
Disturbance	1,30	1,22	1,07	1,07	0,98	0,90	0,82	0,74	0,70	0,67		0,56	0,52	0,48	0,44	0,39	0,35	0,35	0,32	0,32

The deviation diminishes, for both gears, as the admission decreases.

The deviation in forward gear, is very great for the second engine.

as in *Krauss's* engine, (II Pl. XXI, *figs* 1 and 2), a valve r worked by means of the crank t; sometimes, as in the Great Eastern engine, (II Pl. XXIII r), and in *Allan's* regulator, a cylindrical valve, to which the driver imparts directly a double movement of rotation round its axis, and of translation, the working crank being contained between two vertical guides, inclined to the axis. (II Pl. XXII).

The slide, when it is horizontal, is also worked directly, without rod or crank, just like the cylindrical valve; the latter is not, like the slide, rendered tight by the pressure of the steam itself, and its position in the inside of the boiler renders it difficult of access. Arrangements of this sort should not be followed, especially those in which the pressures of the steam on the valve do not balance. It is easy however, to obtain equilibrium, and it will be at once seen that *Allan's* regulator (Pl. IV, *fig.* 27) has this property. When it is closed, the convex surface, m, n, p, q, of the cylinder, is alone subjected to the pressure of the steam, which rushes in through the tube T, into which the valve is continued.

We shall not dwell longer on this organ, which is not so important as its name would lead to suppose. It is not in effect, the regulator which *regulates* the mode of expenditure of the steam : that function is fulfilled, especially with the screw-gearing, by the valve motion, and without the driver having to touch the regulator.

CHAPTER III.

DRAUGHT. — EXHAUST.

§ I. — Preliminaries.

The exhaust is of too much importance to be treated as a simple accessory, and studied summarily. It is by means of the exhaust, which enhances the production of the boiler, that the engine is enabled to develop a power so considerable, with reference to its weight and to its bulk.

111. Making abstraction for the moment, of the part which the steam performs in the cylinders, let us pass at once to that which it plays in connection with the draught.

If the original idea of injecting steam into the chimney, does not belong, as is often stated, to *Pelletan*, he appears at least to have suggested it to M. *Seguin*, who had applied a simple fan, to his first engine. But it was a question, at first, of steam taken directly from the boiler.

"This method, much more advantageous than the fan", says, in effect, M. *Seguin* (*), "*requires the use of steam at a high pressure, and does not allow its elasticity to* "*be utilized.* It must be allowed to escape into the air, after being used, and retains "*the whole of the tension under which it was produced.*"

Better informed, the distinguished engineer was not long in borrowing from England, the profitable idea of the injection of the *exhaust steam*, which was applied, according to M. *D. K. Clark*, as far back as 1827, by M. *Hackworth* to the *Royal-George*, an engine on the *Stockton* and *Darlington* line; but, he adds, there was not much importance attached to it at the time. According to the same writer, *Hackworth* himself had been preceded by *Trevithick*.

What is certain is, that this energetic process was well known in England before 1829, seeing that it was applied to two of the engines at the *Liverpool* Competition.

(*) *De l'influence des chemins de fer*, etc., 1839, page 174.

To feed a furnace, a local disturbance of equilibrium must be determined in the atmosphere, a current must be set up coming from and returning to the atmosphere, after producing its chemical effects, and being deprived more or less completely of its heat, if a steam generator is in question.

This current is produced by the heat taken from the combustion which it maintains, either directly, under the form of heat, as is the case with what is called, improperly enough, *natural* draught; or in the shape of mechanical work, as is the case with fans, and the blast. Let us recall in a few words the principle of natural draught.

The motor force is the difference between the weight of the two columns of air, of the same volume as that of the chimney, at the atmospheric pressure, and having for temperature and specific weight, the one those of the atmosphere, the other, those of the gases inside the chimney.

There is thus an advantage in giving the chimney a large diameter, seeing that the height is reduced in consequence, and the more so as the current passing through it at a lower velocity, its resistances are diminished.

The velocity at the top V'', is determined, in each case, by the condition that the current may not be driven down by the wind; from this results the section of the chimney, supposed constant, and in reality its mean section, reduced from below upwards by conditions of stability, and to take into account the cooling of the gases.

In order to burn per second q lbs of fuel requiring 223,765 cubic feet of air at the external temperature t, a volume which becomes

$$223{,}765\ q\ \frac{1+\alpha t'}{1+\alpha t}$$

at the temperature t' of the chimney, requires a section :

$$\text{S sq. ft} = \frac{223{,}765\ q}{V}\ \frac{1+\alpha t'}{1+\alpha t}.$$

The height h ought to be such that in the unit of time the excess of motor work over the work of the resistances imparts the velocity V to the mass $\frac{\delta S V}{g}$ of gas, δ being its specific weight at the temperature t.

The motor force is :

$$\delta S h[1+\alpha(t'-t)] - S\delta h = \delta S h \alpha (t'-t).$$

The sum of the partial resistances corresponding to the different portions of the passage of the air, from the grate up to the top of the chimney, may

be represented by the weight of a column of air at the inside temperature t' and with the section S; h' being its height, the work of the resistances is $S\delta h' V$, and we have :

$$S\delta\alpha(t'-t)h \times V - S\delta h' V = \frac{S\delta V}{g} \times \frac{V^2}{2},$$

whence

$$V = \sqrt{2g[h\alpha(t'-t) - h']},$$

An equation in which h' is a function of the unknown quantity h, one of the terms of h' representing the resistance proper of the chimney, proportional to its height. Among the other resistances, there is one very variable, difficult to estimate directly, and that due to the nature of the fuel iself, and to the manner in which it is put on. Often besides, the height of the chimney is imposed by a condition independent of the draught : that of expelling the gases and the smoke at a sufficient height (104).

112. *Principle of the draught by the exhaust steam.* In locomotives, the chimney of very small section and rudimentary height, nothing indeed sometimes (8), only determines by itself an insignificant amount of draught; it plays however an important part in the accomplishment of this main function, but only in aiding the expulsion of the air by the steam.

The action of a fluid vein in carrying along the elements of the medium into which it flows, has numerous applications to industrial purposes, some of them very old.

The vein, liquid, steam, or gas, may act upon a liquid, upon a gas, or even on a semi-fluid, as in *Tilghmann's* sand apparatus (Sand-spritz).

In the *trompe*, the water to which gravity has imparted a great velocity, carries over air, with which it forms a mixed current, abruptly stopped and broken by an obstacle, which effecting the separation of the air, is compressed to a capacity which affords it no outlet, but a tuyère. This is a *blowing* apparatus. The idea of this old mountain blowing machine was probably suggested to the inhabitants by the observation of the effects of waterfalls ; the water mixed with air is broken up at the foot of the fall, producing a very violent wind. No one who has walked by the *Staubach* or the *Pissevache* can have failed to remark this, however little he may have desired to be close to these natural trompes, acting in the open air.

In the *Giffard's* injector, it is the steam which aspires and carries over the water, mixes with it in condensing, and determines by its change of state, a current from the *boiler* to the *boiler*.

In the blast, it is the steam which aspires, and carries over the air, and thus, determines a current from the *atmosphere* to the *atmosphere*; the

origin of the disturbance of equilibrium is below the furnace; it is thus an *aspiring* apparatus.

The carrying over of air by the steam may have other objects: for example, to render drinkable, by restoring to it the necessary air, the water obtained by the distillation of sea-water, etc.

The steam which produces the draught might be taken directly from the boiler. It would be so in condensing engines, and such is the case of the locomotive blower (105); but the latter has only had hitherto an accidental, accessory part, although a good driver knows how to take advantage of it, oftener than is supposed. Steam which would have no other functions to fulfil than the draught, would probably only utilize a small fraction of its available work; a question which has however, not yet been sufficiently considered. (132.)

The essential and very remarkable characters of the draught by the exhaust, are: 1st, its production by the steam which has expended, as completely as the conditions of the establishment of the engine allow, its work on the pistons; 2nd, the habitual application to this function, of the whole of the steam expended. It is to this last circumstance that the method of draught in question owes, as we shall shortly see, the property of regulating, of adapting itself without any change, to a variable production of steam, between very wide limits.

It is besides, of little consequence, if the draught imperfectly utilizes the work still available in the exhaust steam (124), seeing that it is a question of work, which, with the locomotive such as it is now, would otherwise be entirely lost.

It will be perhaps objected, that if the condensation in a closed vessel is impracticable with locomotives, one part of the heat, and the *vis viva* carried over by the steam, may at least be collected, and applied to the heating of the water in the tender, as was long done in Germany, by means of M. *Kirchweger's* apparatus (93), or others analogous; that in this case, the steam sent into the chimney constitutes a loss imputable to the mode of draught. The quantity of heat $(\lambda - A\,p\,u)$, above that of water at 0° contained, in 1 lb. of saturated steam, at 9 atmospheres (348°) being 1105,7 units of heat, the heat required in order to form it is 1078.7 units of heat, or 925,7 units of heat, according as the feed-water is at 59° or at 212°. The *theoretical* economy obtained in bringing up, by the condensation of the steam, the water of the tender to its maximum temperature of 212°, is thus 14 per cent.

At starting, the water of the tender being supposed at 59°, and the

exhaust steam at 212°, the latter injected in more or less considerable proportion, brings the mass of water more or less rapidly to this temperature by condensing. From that moment, it is only a question, until the next filling of the tender, of compensating the losses by radiation and leakage, and each pound of steam sent into the tender gives up by condensation, to make up for these losses $q + \rho - 181$ units of heat, or 851 units of heat, seeing that for saturated steam at 212°, $q = 181$ units of heat, and $\rho = 851$ units of heat.

This source of heat was abundant enough to render recourse thereto sufficient, either by turning aside part of the steam, taking advantage of those moments when the normal condition of the draught can be deviated from without disadvantage, that is to say from sending the whole of the exhaust steam into the chimney. This wasthe driver's affair, and he easily succeeded in reconciling the heating of the water with the draught, rendering the first of course subordinate to the second.

If this operation has never entered into general practice, in spite of the economy of fuel which would ordinarily result from it (134), and is now given up, too completely perhaps (134)], the sacrifice is not imposed by the requirements of the draught, but by other reasons, and especially because at this high temperature, feeding already difficult sometimes with pumps(*), would be impossible with *Giffard's* injector, so that if it were a question of choice between this admirable apparatus, and the heating of the water, the decision could not long be doubtful ; it is thus that the condensation of the exhaust steam has been given up simply to adhere to the use of the ordinary heater, which permits the excess of steam in the boiler to be utilized while stationary, or running down average inclines, otherwise it would escape through the safety-valves. This pipe existed also in engines provided with condensing apparatus, which restricted its use, but not the extent of rendering it useless, the circumstances under which they are applied being different.

§ II. — Theory of the blast.

113. The experimental researches on the blast and its effects are not very numerous. The most complete, and most interesting were made almost simultaneously, on the one part by MM. *Nozo* and *Geoffroy* and on the other, by M. *Zeuner*. Those of M. *Prüssmann* had for object the form of the chimney, that is to say, a secondary element in the whole apparatus of the draught.

As to the simple observations made on the rarefaction in the smoke-box, and sometimes also in the fire-box, their crude results were almost without immediate utility for the establishment of the theory of the blast.

One very important side of the question was however long ago elucidated, by numerous observations. We know by the indicator diagrams, that, especially with coal, which allows large blast openings, the back pressure due to the draught caused by the exhaust steam, is scarcely appreciable.

The knowledge, up to that point so imperfect, of the laws of discharge of elastic fluids has already made notable progress, since the introduction into science of the principles of the new branch of mechanics of which it forms the necessary complement, that is to say, thermo-dynamics. It was M. *Zeuner* who, first applied it to the theory of the blast, and his important and useful work (*) shall be our guide in what follows.

In the blast, there are present two currents, at first distinct, the one of steam, the other of gas, which mingle and become one in the chimney.

Let us study successively the laws of discharge of each of these three currents.

a. *Velocity of discharge of the air*. We shall first recall the fundamental formulæ for the flowing of gases and vapours, formulæ which receive continual applications, and ought to be familiar to all engineers. Their application to the very complicated problem of the blast, would lead unfortunately to difficulties of calculation which can only be avoided by being satisfied with simple approximations. This is what M. *Zeuner* did, and he obtained thus, remarkable results, verified by experiment, which also confirmed at the same time, the sufficient exactness of his hypotheses.

Let us consider first, a fluid flowing out of a reservoir, in which a piston maintains a constant pressure, through an orifice connected with the sides by a rounded surface, the section of which is very small relatively to that of the recipient.

Let (**) : p_1 be the pressure per unit of surface which exists throughout the reservoir or at least in all that portion in which the elements have yet only a very small velocity compared to that which they take at the opening; p_2 ($< p_1$) the external pressure; p the pressure variable from p_1 to p_2

(*) *Das Locomotiven Blas-Rohr*. — 80. *Meyer* and *Zeller*, *Zurich*.

(**) In all that regards the mechanical theory of heat, we shall keep to the notations made use of by *Clausius* in the Memoirs which have contributed so much to the progress of this new branch of mechanics; which notations are at the same time generally employed by M. *Zeuner*.

throughout the extent of the trajectory of an element, from the origin of its movement up to the opening; w its velocity at the latter; v_1, v_2, v, the volumes of the unit of weight corresponding to the pressures p_1, p_2, p.

The velocity w is given by the known equation of work:

$$\frac{w^2}{2g} = p_1 v_1 - p_2 v_2 + \int_{v_1}^{v_2} p\,dv, \text{ or} \tag{1}$$

$$d\left(\frac{w^2}{2g}\right) = -d(pv) + p\,dv \tag{2}$$

for a permanent gas to which the laws of *Mariotte* and of *Gay-Lussac* are applicable (or, more exactly, for the *theoretical* gas, named by M. *Regnault* (*): *ideal fluid*), we have, t and t_1 being the temperatures corresponding to the states p, v; p_1, v_1, and α the coefficient of expansion, nearly constant, or $\frac{1}{460}$ per degree (F.) of the volume at 32°:

$$\frac{v}{v_1} = \frac{p_1}{p}\,\frac{1+\alpha t}{1+\alpha t_1} = \frac{p'}{p}\,\frac{\frac{1}{\alpha}+t}{\frac{1}{\alpha}+t_1}, \text{ or } \frac{pv}{\frac{1}{\alpha}+t} = \frac{p_1 v_1}{\frac{1}{\alpha}+t_1};$$

$\frac{p\,v}{\frac{1}{\alpha}+t}$ is then for each gas a constant quantity R, whence

$$pv = \mathrm{R}\left(\frac{1}{\alpha}+t\right) = \mathrm{R}(460+t) = \mathrm{RT},$$

T being the temperature reckoned by taking for zero 460° (F.), which is called the *absolute* temperature. We have thus in (2), $d\,(p\,v) = \mathrm{R}\,d\,\mathrm{T}$.

As to the second term, $p\,dv$, it is not an exact differential: a body may pass in an infinity of ways, through an infinity of intermediate states, from a state: p_1, v_1, t_1, to another p_2, v_2, t_2. In order to form the integral $\int_{v_2}^{v_2} p\ dv$, it is necessary to know the law according to which the fluid passes from the temperature t_1 which corresponds to the first state, to the temperature t_2 which corresponds to the second.

When the unit of weight of a body receives a quantity of heat $d\,\mathrm{Q}$, the latter is divided, in general, into two parts; the one $d\,\mathrm{U}$ which causes the internal work to vary (work of *oscillation*, and work of *disaggregation* of *Clausius*), the other, which produces the external force $p\ dv$, exerted, by the body which expands, on the medium which envelopes and presses it. We have then, A being the calorific equivalent of work or $\frac{1}{763}$ of a unit of heat:

$$d\mathrm{Q} = d\mathrm{U} + \mathrm{A}p\,dv, \text{ whence } p\,dv = \frac{d\mathrm{Q} - d\mathrm{U}}{\mathrm{A}}.$$

(*) Relation des Expériences, etc. vol. III, p. 559.

Now c_1 being the specific heat by weight, and in constant volume, we have, according to the definition itself of dU :

$$dU = c_1 dt = c_1 dT, \quad \text{whence} \quad pdv = \frac{dQ - c_1 dT}{A}.$$

but according to a theorem of *Clausius* (*), c_1 and the specific heat at a constant pressure c are connected by the relation $c - c_1 = AR$, whence

$$pdv = \frac{dQ - cdT}{A} + RdT.$$

carrying into (2) the values of $-d(pv)$ and of dpv,

$$d\left(\frac{w^2}{2g}\right) = -RdT + \frac{dQ - cdT}{A} + RdT = \frac{dQ - cdT}{A}. \tag{3}$$

In order to apply these expressions to the determination of w, three principal hypotheses may be made, that is to say, supposing constant up to the opening :

1st. The specific weight, or, what comes to the same thing, its inverse, the relative volume v of the fluid;

2nd. The temperature;

3rd. The total heat Q.

1*st. Constant specific weight :*

$$dv = 0, \quad \text{which reduces (2) to} \quad d\left(\frac{w^2}{2g}\right) = -d(pv_1) = -v_1 dp,$$

whence $$\frac{w^2}{2g} = -v_1 p + \text{constant}.$$

At the origin, $p = p_1$, $w = 0$, whence constant $= v_1 p_1$,

and $$\frac{w^2}{2g} = v_1(p_1 - p),$$

and for $p = p_2$, and calling γ the specific weight, whence $v_1 = \frac{1}{\gamma}$,

$$\frac{w^2}{2g} = \frac{p_1 - p_2}{\gamma}. \tag{4}$$

This constancy of the density, as long as the difference $p_1 - p_2$ of the pressures is not too great, has been verified for air by former experiments made by M. *Pecqueur* and discussed in 1845 by M. *Poncelet.* (**)

Within these limits, the elastic fluid behaves like a liquid.

This supposes besides a determinate ratio between the absolute temperatures T_1 in the reservoir, and T_2 at the opening, seeing that we then have :

$$p_1 v_1 = RT_1, \quad p_2 v_2 = RT_2, \quad \text{whence} \quad \frac{T_1}{T_2} = \frac{p_1}{p_2}.$$

(*) 1st Memoir. p. 44. Zeuner, théorie mécanique de la chaleur.

(**) Comptes rendus de l'Académie des sciences. v. VI, 1845.

p_1 being $> p_2$, T_1 is $> T_2$. The fluid cools during its efflux, and since by hypothesis, it does not expand, and that, on this account, there is no transformation of heat into external work, the unit of weight must lose a quantity of heat:

$$c_1(T_1 - T_2), \quad \text{or} \quad \frac{c_1(p_1 - p_2)v_1}{R} = \frac{c_1(p_1 - p_2)}{\gamma R};$$

a value which is deduced almost immediately from the relation:

$$dQ = -c_1 dT + A p dv,$$

which reduces them to,

$$dQ = c_1 dT \quad \text{or} \quad Q = c_1(T_1 - T_2).$$

2*nd. Hypothesis of constant temperature:*

$dT = 0$. The equation (3) is reduced to $A d\left(\frac{w^2}{2g}\right) = dQ$, whence $A\frac{w^2}{2g} = Q$,

and the equation $dQ = dU + Apdv = c_1 dT + Apdv$ to : $dQ = Apdv = Apv\frac{dv}{v}$,

and on account of $pv = RT$, to :

$$dQ = ART\frac{dv}{v}.$$

and as $pv = RT = \text{constant}$, gives $pdv + vdp = 0$,

or $\frac{dv}{v} = -\frac{dp}{p}$, we have

$$dQ = -ART\frac{dp}{p} \quad \text{and} \quad Q = ART \log n p + \text{constant};$$

for $p_2 = p_1$, $Q = 0$, then constant $= ART \log n\, p_1$,

and $$Q = ART \log n \frac{p_1}{p},$$

and for $p = p_2$, $Q = ART \log n \frac{p_1}{p_2}$; carrying into $\frac{Aw^2}{2g} = Q$,

$$\frac{w^2}{2g} = RT \log n \frac{p_1}{p_2} = p_1 v_1 \log n \frac{p_1}{p_2}, \quad \ldots \quad (5)$$

equation which gives the velocity.

$A\frac{w^2}{2g} = Q$, is the quantity of heat that the unit of weight ought to receive, in order that its temperature may remain constant during the efflux, this quantity of heat is transformed entirely into *vis viva* of mass, in order to generate the velocity w with which the gas passes through the opening.

The expression (5) of the work which the unit of weight produces, in expanding from p_1 to p_2, is the old logarithmic formula deduced from *Mariotte's* law: $p\,v$ = constant; and we see that, to be exact, it would be necessary for the gas to receive during its efflux, a quantity of heat equivalent to this work.

3rd. Hypothesis of the efflux without addition or subtraction of heat.

In the equation (3) $d\left(\frac{w^2}{2g}\right)=\frac{dQ-cdT}{A}$, it is then dQ which is o,

and the equation gives $\frac{w^2}{2g}=-\frac{c}{A}T+\text{constant}$.

At the origin, $w=o$, $T=T_1$, whence constant $=cT_1$,

and $\frac{w^2}{2g}=\frac{c}{A}(T_1-T)$; at the opening, $T=T_2$; then $\frac{w^2}{2g}=\frac{c}{A}(T_1-T_2)$.

T_1, the temperature in the reservoir, is given, or is deduced directly, p, and v, being known, from the relation:

$$T_1=\frac{p_1v_1}{R}=\frac{p_1}{\gamma R}.$$

It is necessary to determine T_2; the general relation

$$dQ=c_1dT+Apdv$$

becomes for $dQ=0$, on account of $pv=RT$, which gives:

$$pdv+vdp=RdT, \quad \text{et} \quad Apdv=ARdT-Avdp,$$

$0=c_1dT+ARdT-Avdp$, and replacing v by $\frac{RT}{p}$ and AR by $c-c_1$;

$$o=cdT-(c-c_1)T\frac{dp}{p}, \qquad \text{or} \qquad c\frac{dT}{T}=(c-c_1)\frac{dp}{p},$$

whence $c\log n\,T=(c-c_1)\log n\,p+\text{constant}$;

for $T=T_1$, $p=p_1$; then constant $=c\log n\,T_1-(c-c_1)\log n\,p_1$,

carrying forward, and reducing, and making:

$$c\log n\frac{T_1}{T}=(c-c_1)\log n\frac{p}{p_1},$$

$$p=p_2, \quad T=T_2: \log n\frac{T_2}{T_1}=\left(1-\frac{c_1}{c}\right)\log n\frac{p_2}{p_1},$$

and putting $\frac{c}{c_1}=K$,

$$\log\frac{T_2}{T_1}=\frac{K-1}{K}\log n\frac{p_2}{p_1} \quad \text{et} \quad T_2=T_1\left(\frac{p_2}{p_1}\right)^{\frac{K-1}{K}};$$

If in this equation we replace T_2 by $\frac{p_2\,v_2'}{R}$ and T_1 by $\frac{p_1\,v_1}{R}$ it becomes

$$\frac{p_2v_2}{p_1v}=\left(\frac{p_2}{p_1}\right)^{\frac{K-1}{K}}, \qquad \text{or} \qquad \left(\frac{p_2v_2}{p_1v_1}\right)^K=\left(\frac{p_2}{v_2}\right)^{K-1},$$

or

$$\frac{p_2}{p_1}\left(\frac{v_2}{v_1}\right)^K=1, \quad \frac{p_2}{p_1}=\left(\frac{v_1}{v_2}\right)^K, \qquad \text{or} \qquad pv^K=\text{constant} \quad . \quad . \quad .$$

That is to say, the expression known under the name of *Laplace's* formula, which approximates more to *Mariotte's*: $p\,v =$ constant, in proportion as K approaches unity.

Carrying into $\frac{w^2}{2g}$ the values of T_1 and of T_2,

$$\frac{w^2}{2g} = \frac{c}{A}\frac{p_1}{\gamma R}\left[1-\left(\frac{p_2}{p_1}\right)^{\frac{K-1}{K}}\right] \quad \ldots\ldots\ldots \quad (6)$$

For weak values of $p_1 - p_2$, this relatively complicated expression gives results differing little from those to which the first hypothesis leads, that of the constancy of the specific weight. We may then keep to the expression (4)

$$\frac{w^2}{2g} = \frac{p_1 - p_2}{\gamma}$$

to calculate the velocity with which the atmospheric air rushes through the tubes into the smoke-box, where the jet of steam maintains a pressure that has to be determined, but which is always little below p_1 that is to say the atmospheric pressure.

114. *b. Velocity of efflux of saturated steam, dry or mixed with water.* The characteristic property of vapours in contact with their liquid is that their temperature determines their pressure and specific volume. In order to calculate the velocity with which steam flows out of a generator where it is in contact with its liquid, it was formerly considered sufficient, either to apply, as for gases, the formula (5)

$$\frac{w^2}{2g} = p_1 v_1 \log\frac{p_1}{p_2},$$

which supposes the temperature constant, or to admit with M. *Redtenbacher*, that the steam remains saturated, but that no condensation is effected during the efflux, the specific weight being besides given by *Navier's* empirical formula $\beta(a+p)$. But the third hypothesis, that of the efflux without addition or subtraction of heat approximates much more to the reality.

The general equation (2) and the relation

which reduces it then to $$pdv = \frac{dQ - dU}{A}$$

$$pdv = -\frac{dU}{A};\ \text{give :}$$

$$d\left(\frac{w^2}{2g}\right) = -d(pv) - d\frac{U}{A} \quad \ldots\ldots\ldots \quad (7)$$

At a point of the trajectory of an element where the pressure has a value p comprised between p_1 and p_2, and the temperature, the corresponding value,

let be x the weight of the steam, and consequently $1 - x$ the weight of water contained in the unit of weight of the mixture; s the specific volume of the steam, σ that of the water; the specific volume v of the mixture is:

$$v = xs + (1 - x)\,\sigma = x\,(s - \sigma) + \sigma,$$

or neglecting the second term against the first and putting $s - \sigma = u$ (*),

$$v = x\,(s - \sigma) = xu,$$
$$pv = xpu;\ -d(pv) = d(xpu).$$

Let us seek the second term $-\frac{dU}{A}$ of equation (7) specifying, as is indispensable, in order that the problem may be determinate, the conditions in which the change of the state of the water is effected.

Let there be, in a cylinder, in which a piston maintains a pressure p, 1lb. of water at 32°; in order to transform this weight of water into saturated steam, at the same pressure p, and at the corresponding temperature t, it is necessary :

1st, to bring the water to $t°$, which requires an amount of heat $\int_0^t c\,dt$; neglecting the expansion of the water, there is no external work produced, and $q = \int_0^t c\,dt$ is the whole amount of heat necessary to bring the water from $o°$ to $t°$; it bears the name of *heat of the liquid.*

2nd, by continuing to add heat, to form steam, which raises the piston. The heat r necessary to reduce into steam under the pressure p and at the correlative temperature t, the unit of weight of water taken at the same pressure and at the same temperature, includes:

a, that which is transformed into external work on the piston; the water passing from the volume σ to the volume t, the increase is $s - \sigma = u$; and the work, $p\,u$; equivalent, heat A $p\,u$; heat which was necessary in order to form the steam, but which does not remain therein. This is the *external latent heat.*

b, that ρ, which remains in the steam, but in the latent state, seeing that there is no rise of the temperature; this is the *internal latent heat.* The

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(*) As long as σ is neglected against $x(s - \sigma)$ σ is *a fortiori* capable of beng neglected against s since x is at the most $= 1$; which reduces the equation to $v = xs$. We keep however the expression $v = x\ (s - \sigma) = xu$ in order to leave u the exact signification which has been given to it in the useful numerical tables due to M. *Zeuner*, and attached to his *Mechanical Theory of Heat.*

At 5 atmospheres we have, $u = 12.81$ c. ft , and at 9 atmospheres $u = 7.36$ c. ft. σ, always differing very little from 0.0353 c. ft., is thus very small against u, even for high pressures.

total heat λ which has been required to supply to the pound of water at 32° is thus : $\lambda = q + r = q + A\,p\,u + \rho$; and that which it retains is : $q + \rho = \lambda - A\,p\,u$. The quantity of heat contained in the unit of weight of the mixture at $t°$, beyond that which this unit contained in the state of water at 0°, is thus: $\int_0^t c\,dt + x\,\rho$. Such is the expression of the internal heat U; then $d\,U = c\,d\,t + d\,(x\,\rho)$. Carrying into (7), the values of $d(pv)$ and of $d\,U$, it becomes :

$$\frac{dw^2}{2g} = -d(xpu) - \frac{cdt}{A} - \frac{d(x\rho)}{A},$$

or on account of $\rho + Apu = r$, and $dt = dT$,

$$Ad\frac{w^2}{2g} = -cdT - d(xr),$$

whence $$A\frac{w^2}{2g} = -cT - xr + \text{constant}.$$

T_1, x_1, r_1, being the values of T, x and r in the boiler where $w = 0$,

we have $$\text{constant} = cT_1 + x_1r_1,$$

And carrying on $$\frac{Aw^2}{2g} = -cT - xr + cT_1 + x_1r_1;$$

and T_2, x^2, r_2, being the values which T, x, r, take at the opening, where the velocity is w :

$$A\frac{w^2}{2g} = c(T_1 - T_2) + x_1r_1 - x_2r_2 \quad \ldots\ldots\ldots \quad (8)$$

r_1 and r_2 can be calculated by the empirical formula of M. *Clausius:*

$$r = 607 - 0{,}708\ t = 800{,}28 - 0{,}708\,T,$$

or more exactly by the relation $r = \lambda - q$, λ and q being given by M. *Regnault's* formula:

$$\lambda = 606{,}5 + 0{,}305\,t, \quad q = \int_0^t c\,dt = t + 0{,}00002\,t^2 + 0{,}0000003\,t^3.$$

The temperatures t_1 and T_2, t_2 and T_2 corresponding to the pressures p_1 and p_2, are given by the tables, for which we are indebted to the same physicist. x_1 the initial value, is given, and equal to 1, if in the boiler the steam contains no liquid water. As to x_2 its value is given by a relation due to M. *Clausius*, and is one of the most remarkable in thermo-dynamics, of which, in effect, it confirms the principles, by bringing out, as one of their consequences, a fact inexplicable by the old theory of steam engines, that is to say the condensation which accompanies expansion. We shall

return to this point when treating of the motor. The relation in question is (*):

$$w^2 = \frac{T_2}{r_2}\left(\frac{x_1 r_1}{T_1} + c \log n \frac{T_1}{T_2}\right). \quad \ldots \quad (9)$$

It proves that x_2 differs, in general, from x_1.

Barrying forward in (8),

$$A\frac{w^2}{2g} = c(T_1 - T_2) + x_1 r_1 - \frac{T_2}{T_1} x_1 r_1 - cT_2 \log n \frac{T_1}{T_2}$$

$$= c(T_1 - T_2) + x_1 r_1 \left(\frac{T_1}{T_1} - \frac{T_2}{T_1}\right) - cT_2 \log n \frac{T_1}{T_2}$$

$$= \left(c + \frac{x_1 r_1}{T_1}\right)(T_1 - T_2) - cT_2 \log n \frac{T_1}{T_2} \quad \ldots \quad (10)$$

Simplified formula. As $\log n \frac{T_1}{T_2} = \log n \left(1 + \frac{T_1}{T_2} - 1\right) = \log n \left(1 + \frac{T_1 - T_2}{T_2}\right)$,

if the fraction $\frac{T_1 - T_2}{T_2}$ is small enough to allow us to stop at the first term of the development of the logarithm into series, we have :

$$A\frac{w^2}{2g} = \left(c + \frac{x_1 r_1}{T_1}\right)(T_1 - T_2) - c(T_1 - T_2) = \frac{x_1 r_1}{T_1}(T_1 - T_2), \quad (10\ bis)$$

a very simple expression, but applicable only to very small differences of temperature.

The formula usual hitherto, that is to say, the one (4, No. 113), establishes for gases, and on the hypothesis of the constancy of the temperature, gives for steam, very exaggerated values of the velocity of efflux. In order to maintain its temperature in expanding, it would have to be super-heated; now, not only does it remain saturated, when passing through the opening, but a condensation even takes place (the more abundantly, the higher the pressure), which doubly reduces its relative volume, and consequently its velocity.

115. *Weight of steam discharged through an opening of section F square inches.* The specific volume of the mixture of steam and water which flows through the orifice with the velocity w, given by equation (10), is : $x_2 u_2$.

The volume of the weight Q lbs. discharged per second, is then : $Q x_2 u_2$; it has also for expression.

$$Fw, \quad \text{then} \quad Q = \frac{Fw}{x_2 u_2}.$$

T is given; x_2 and w are known [(9) and (10)]; u_2 is deduced from the relation

$$\lambda_2 = q_2 + \rho_2 + Ap_2 u_2,$$

(*) *Poggendorff's Annalen*, vol. XCVII, page 460.

the internal latent heat ρ_2 being calculated by the empirical formula of M. *Zeuner* (*):

$$\rho_2 = 1035.5 - 0.791\, t_2 \text{ (*)},$$

whence $$Ap_2u_2 = 55.60 + 1.096\, t_2 - 0.00002\, t_2^2 - 0.0000003\, t_2^3.$$

u_2 may also be calculated, with sufficient exactness, by this other empirical formula:

$$Ap_2u_2 = 54.82 \log \text{nat.} \frac{T_2}{100}.$$

For slight differences of pressure, the theoretical expenditure Q can also be calculated by the empirical formula (**):

$$Q = 543.8 F \sqrt{n - 0.941}$$

in which n is, in atmospheres, the absolute pressure in the boiler, and consequently the quantity under the radical nearly equal to the effective pressure.

This formula agrees well with the preceding one, $Q = \frac{Fw}{x_2 u_2}$

In order to have the real expenditure, the coefficient of reduction may be taken equal to 0,95, on account of the conical shape of the blast-opening; the approximate formula becomes then:

$$Q = 516.6 F \sqrt{u - 0.941}$$

116. c. *Mixed current; application to the blast; difficulties of this application, necessity of simplifying the terms of the question.* The preceding formulæ solve the question relating to the efflux of air and of saturated steam, dry or mixed with water, when the external pressure p_2 is known, as well as the internal pressure p_1. But when it is a question of the blast, the immediate effect of which is to produce a depression in the capacity, into which rush, on the one part, the steam coming from the cylinders, and on the other, the gases leaving the tubes, the pressure p_2 which is set up in that capacity, the smoke-box, is not known, and it must be determined at first, in order to solve the main question, which is this: *What is the weight of atmospheric air aspired by a given weight of steam, escaping under the pressure p?*

In order to produce a given weight of saturated steam, dry, or containing a determinate proportion of water, at a given pressure, an amount of fuel must be consumed proportional to the first. The quantity of air necessary to completely consume this second weight, is proportional to it, and is thus also to the first.

(*) *Théorie mécanique de la chaleur*, page 273.

(**) *Das Locomotiven Blas-Rohr*, page 217.

The draught, in whatever way it may be produced, ought thus to satisfy as much as possible this condition, that there may be, for each given state of the system, a constant ratio between the weight of the steam produced, and the weight of air absorbed in the same time. Now this result, which might have seemed a theoretical limit, very difficult to reach, is realized by the mode of obtaining the draught in locomotives, and which has for essential character, the regular injection into the chimney, of the *whole* of the steam produced. Such is the main point established, as we shall see, by M. *Zeuner*, and it already presents a clear view of the functions of this all important organ of the locomotive.

Let us consider then (Pl. V, *fig*, 1), a capacity C, into which rush, on the one hand, steam out of the blast-pipe, with the velocity w, through an orifice F, above which the pressure is p, on the other, the gases leaving the tubes, the total section of which is F_2, with a velocity w_2. These two currents mix together in the chimney, of section F_1, and there form a mixed current which flows out with the velocity w_1.

As to what concerns the movement of the gases from the ash-pan to the smoke-box, the excess of atmospheric pressure p_0, over the pressure p_x, is always low enough for us to admit that the formula (4) is applicable; so that w_2 being the theoretical velocity of the gases passing through the smoke-box ferrules, and γ_2 the specific weight of the atmospheric air at the external pressure and temperature, we have,

$$\frac{w_2^2}{2g} = \frac{p_0 - p_x}{\gamma_2}.$$

In order that w_2 may express the real velocity, the first member must be multiplied by a coefficient $1 + \chi$, $\chi \frac{w^2_2}{g}$ being the loss of *vis viva* due to the resistances which act on the gaseous current, during its whole journey from the ash-pan to its front extremity (smoke-box side) of the tubes. We have thus:

$$(1 + \chi)\frac{w_2^2}{2g} = \frac{p_0 - p_x}{\gamma_2}.$$

But for the jet of steam, the expression (10) of the velocity of efflux is much too complicated to be applied in the actual case; and in comparing the values of w, to which it leads for given values of p_0 and p_x, and for dry saturated steam, with those given by formula (4), the specific weight γ being calculated by *Navier's* formula (or, more exactly, M. *de Pambour's*), M. *Zeuner* found the deviations to be very great, even for differences of pressure less than those which occur in practice, between the blast and the smoke-box.

He ascertained, at the same time, that within the limits of these mean pressures, the one always little above, the other always very little below the atmospheric pressure, the values of $\frac{w^2}{2g}$ are represented very exactly by the expression $\frac{p-p_x}{\gamma}$, γ being always a function of the pressure, of the same form $\beta(a+p)$ as *Navier's* formula, but the numerical coefficients β and a having quite other values. The pressure p being expressed in pounds on the square inch, and γ being the weight, in pounds, of the cubic foot of saturated steam at that pressure, these values are:

$$\beta = 0.00002497, \quad a = 14.357 \text{ instead of } \beta = 0.00004713, \quad a = 3.017\ (*).$$

For these last we have : $\gamma = 0.1421 + 0.0000471\ p_1$ that is to say the empirical formula of M. *de Pambour*, an expression less inexact, within the ordinary limits of tension in non-condensing engines, than *Navier's* which is: $\gamma = 0.09 + 0.0000484\ p$.

The theoretical velocity of efflux of the steam at the orifice of the blast pipe can thus be calculated by the expression

$$\frac{w^2}{2g} = \frac{p-p_x}{\gamma},$$

but by giving γ the value 0.00002497 (14.357 + p) which has nothing in common with the specific weight; and the expression itself is no longer anything but a simple empirical formula. In order that w may represent the real velocity and not the theoretical, it is necessary to multiply the first member by a coefficient $1+\zeta$, $\zeta\frac{w^2}{2g}$ representing the loss of pressure due to the resistances, and we have.

$$(1+\zeta)\frac{w^2}{2g} = \frac{p-p_x}{\gamma}.$$

The unitof weight of steam rushing out of the blast-pipe with this velocity w, possesses a *vis viva* $\frac{w^2}{g} = 2\frac{(p-p_x)}{\gamma(1+\zeta)}$.

It enters into the chimney, where the pressure is p_x at the entrance, p_o (atmospheric pressure) on leaving, and takes a velocity therein w_1; by the fact of the change of pressure it loses a *vis viva* equal to that which it would

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(*) For $p = 14.70$ lbs. *Navier's* formula gives 0.039 lb for the weight of the cubic foot, and *Zouner's* function 0.038 lb. For $p = 73.49$ lbs, the first gives, 0.16 lb and the second gives 0.17 lb.

The values of the weight of the cubic foot $\gamma = \frac{1}{u} = \frac{1}{s-\sigma}$, deduced by the mechanical theory of heat are respectively : 0.042 lb, and 0,17 lb.

gain by rushing out in the other direction, under the same difference of pressure, that is to say $\frac{(2p_0 - p_x)}{\gamma'}$, γ being the function indicated just now of the pressure p_0.

But here, especially, it is indispensable to simplify the elements of the question by plausible hypotheses. The composition and the specific weight of the mixture vary from the fire-box to the chimney, and from one point to the other of the first. Taking into consideration the slight difference of the pressures p_0 and p_x we may: 1st, admit that at no part is there any abrupt change of density: 2nd, substitute for the real and heterogeneous fluid that fills the smoke-box and the chimney, a *mean* fictive fluid, having throughout, whatever may be the proportions of gas and steam, the same specific weight γ_1; 3rd, admit that, always on account of the slight difference between the pressures p_0, p_x, the formula of efflux applicable to the gas, may here be extended to the steam. We are thus brought to consider two currents of the same nature, and of the same specific weight, γ_1, forming in the chimney, by their mixture, a current of the same density as each of them.

As has been already said, these hypotheses have been borne out by the experimental verification of the laws to which they lead, γ' may thus be replaced by γ_1 in the above expression

$$\frac{2(p_0 - p_x)}{\gamma'};$$

but that is only allowable, once again, because the difference of the pressures p_0 and p_x is always very slight. It is not the same with regard to $p - p_x$, and it is on this account that it is necessary to keep for γ the indicated signification and value, in the expression

$$\frac{w^2}{g} = \frac{2(p - p_x)}{\gamma(1 + \zeta)},$$

which gives the velocity of efflux of the steam, under the pressure p_1 at the blast-orifice.

The steam undergoes a second loss of *vis viva* due to the abrupt passage of the velocity from w to w_1. This loss may be calculated by *Borda's* method, that is to say by applying *Carnot's* theorem, an application the more natural as the influence of the pressure on the specific weight is neglected.

"It seems to us impossible", wrote M. *Poncelet* in 1845 (*), "to bring into doubt the legitimacy of the method *Borda* proposed for estimating the loss of *vis viva*. *Bernouilli*

(*) Report, already quoted, on M. *Pecqueur's* experiments.

himself perfectly appreciated what takes place, in abrupt changes of velocity, something analogous to that which takes place in the shock of bodies deprived of elasticity; but *Bernouilli* did not take upon himself to deduce therefrom the consequence since admitted by *Borda*, that the loss of *vis viva* is properly measured by to the velocity lost, and he limits himself to estimating it according to the difference of the *vires vivæ* which takes place before and after the abrupt change."

The extension, by way of analogy, of *Carnot's* theorem, to circumstances very different from those to which it is rigorously applicable, was however arbitrary; M. *Resal* has filled up a void by establishing the legitimacy of this extension by means of simple considerations, in respect of which we must restrict ourselves to referring the reader (*).

The *vis viva* possessed by the unit of weight of the steam, in the chimney, is thus

$$\frac{w^2}{g} - \frac{2(p_0 - p_x)}{\gamma_1} - \frac{(w - w_1)^2}{g};$$

in the same way, the unit of weight of gas, the velocity of which is w_0 in the smoke-box, and w_1 (like that of the steam) in the chimney, possesses in the latter a *vis viva*;

$$\frac{w_0^2}{g} - \frac{2(p_0 - p_x)}{\gamma_1} - \frac{(w_0 - w_1)^2}{g}.$$

The section of the smoke-box being very much greater than that of the tubes, it may be admitted that the gases, in passing out of these latter lose their velocity almost entirely, and consequently w_0 may be neglected, which reduces the above expression to:

$$-\frac{2(p_0 - p_x)}{\gamma_1} - \frac{w_1^2}{g}.$$

Q being the weight of steam discharged, Q_2 the weight of the air drawn in, the *vis viva* of the mixture in the chimney is:

$$Q\left[\frac{w^2}{g} - \frac{2(p_0 - p_x)}{\gamma_1} - \frac{(w - w_1)^2}{g}\right] + Q_2\left[-\frac{2(p_0 - p_x)}{\gamma_1} - \frac{w_1^2}{g}\right];$$

it evidently has for expression:

$$(Q + Q_2)\frac{w_1^2}{g}.$$

Equating and reducing, it becomes

$$\frac{p_0 - p_x}{\gamma_1} = \frac{1}{g}\left(\frac{Q}{Q + Q_2} w w_1 - w_1^2\right). \quad \ldots \quad (11)$$

We have in the hypotheses admitted

$$Q = F w \gamma_1, \quad Q_2 = F_2 w_2 \gamma_1, \quad Q + Q_2 = F_1 w_1 \gamma_1,$$

(*) *Traité de mécanique générale*, vol. II, p. 296 and foll. — *Gauthier-Villars. Paris*, 1874.

whence $$\frac{Q}{Q+Q_2}=\frac{Fw}{F_1w_1},$$

and putting $\frac{F_1}{F}=m$, $\frac{Q}{Q+Q_2}=\frac{w}{mw_1}$; and carrying into . . (11)

$$\frac{p_0-p_x}{\gamma_1}=\frac{1}{g}\left(\frac{w^2}{m}-w_1^2\right). \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11')$$

From the above values of Q, Q_2, $Q + Q_2$, we obtain

$$w_1=\frac{F}{F_1}w+\frac{F_2}{F_1}w_2=mw+\frac{F_2}{F_1}w_2, \quad \text{and putting } \frac{F_2}{F}=n,$$

$$w_1=mw+\frac{n}{m}w_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

The first member of the equation (11′) may be written by multiplying and dividing by γ_0 (the specific weight of mercury), and adding and subtracting p;

$$\frac{p_0-p_x}{\gamma_1}=\frac{\gamma_0}{\gamma_1}\left(\frac{p-p_x}{\gamma_0}-\frac{p-p_0}{\gamma_0}\right);$$

the two terms between brackets are the heights of mercury which measure the pressure $p-p_x$, and $p-p_0$; designating them by x and h equation (11 bis)

becomes $$\frac{\gamma_0}{\gamma_1}(x-h)=\frac{1}{g}\left(\frac{w_2}{m}-w_1^2\right);$$

by replacing w_1 by its value (12),

$$\frac{\gamma_0}{\gamma_1}(x-h)=\frac{1}{m^2g}[(m-1)w^2-n^2w^2-2nww_2]. \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

In the same way, by multiplying and dividing its first member by γ_0:

the equation $\frac{p-p_x}{\gamma}=(1+\zeta)\frac{w^2}{2g}$ becomes : $\frac{\gamma_0}{\gamma}x=(1+\zeta)\frac{w^2}{2g}$,

whence $$w=\sqrt{\frac{\gamma_0}{\gamma}\cdot\frac{2gx}{1+\zeta}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

Lastly by multiplying and dividing its second member by γ_0, and adding and subtracting p and p_0:

the equation $$(1+\chi)\frac{w_2^2}{2g}=\frac{p_0-p_x}{\gamma_2}$$

becomes : $$(1+\chi)\frac{w_2^2}{2g}=\frac{\gamma_0}{\gamma_2}\left(\frac{p-p_x}{\gamma_0}-\frac{p-p_0}{\gamma_0}+\frac{p_2-p_0}{\gamma_0}\right).$$

Now the two first terms within brackets, are respectively x and h; as to the third, the pressure p_2 of the gases in the tubes, a pressure greater than x, differs little enough from the atmospheric pressure p_0 to allow this term to be neglected against the difference $\frac{p_0-p_x}{\gamma_0}$ of the two others; the equation thus gives:

$$w_2 = \sqrt{\frac{2g(x-h)}{1+\chi}\frac{\gamma_0}{\gamma_2}} \quad \ldots\ldots\ldots\ldots \quad (15)$$

Carrying into (13) the values (14) and (15) of w and w_2, and putting for shortness

$$\frac{\gamma}{\gamma_1}(1+\zeta) = \alpha', \quad \text{and} \quad \frac{\gamma(1+\zeta)}{\gamma_2(1+\chi)} = \beta',$$

we have

$$[\alpha' m^2 - 2(m-1) + 2\beta' n^2]x + 4n\sqrt{\beta'(x-h)x} = \alpha' m^2 h + 2\beta' n^2 h,$$

which may be written

$$x\left[\alpha' m^2 - 2(m-1) + 2\beta' n^2 + 4n\sqrt{\beta'\frac{(x-h)}{x}}\right] = \alpha' m^2 h + 2\beta' n^2 h.$$

Now from an easy discussion of the values present, we deduce that the term which contains the radical may be neglected. The equation then falls to the first degree, and gives :

$$x = \frac{(\alpha' m^2 + 2\beta' n^2)h}{\alpha' m^2 - 2(m-1) + 2\beta' n^2} \quad \ldots\ldots\ldots\ldots \quad (16)$$

Resuming the values $Q = F\ w\ \gamma_1$, $Q_2 = F_2\ w_2\ \gamma_1$

whence $\frac{Q_2}{Q} = \frac{n w_2}{w}$, and because of (14) and (15), $= n\sqrt{\frac{\gamma}{\gamma_2}\frac{1+\zeta}{1+\chi}\frac{x-h}{x}}$

$$= n\sqrt{\beta'\frac{x-h}{x}}; \quad \ldots\ldots\ldots\ldots \quad (17)$$

now (16) gives :

$$x - h = \frac{2(m-1)h}{\alpha' m^2 - 2(m-1) + 2\beta' n^2}. \quad \ldots\ldots\ldots\ldots \quad (18)$$

and dividing member by member by (16),

$$\frac{x-h}{x} = \frac{2(m-1)h}{\alpha' m^2 + 2\beta' n^2}.$$

carrying into (17),

$$\frac{Q_2}{Q} = n\sqrt{\beta'\frac{2(m-1)}{\alpha' m^2 + 2\beta' n^2}},$$

and replacing α and β by their values,

$$\frac{Q_2}{Q} = n\sqrt{\frac{2(m-1)}{\frac{\gamma_2}{\gamma_1}(1+\chi)m^2 + 2n^2}} \quad \ldots\ldots\ldots\ldots \quad (19)$$

h, or $\frac{p-p_0}{\gamma_0}$, has disappeared.

The weight of air Q_2 aspired by a *given weight* Q of steam, is thus independent of the pressure p of the latter; neither does it depend on their rarefaction, $p_0\ p_x$ in the smoke-box, and the value of which $x - h$, is proportional to h (18), and, for given values of m and n, values which determine very nearly those of γ, ζ, the first weight is proportional to the second ; that is to say that the condition indicated above (same number) as the object

of a good draught, is very nearly fulfilled by the blast, as it is applied to locomotives.

It will be remarked that γ has disappeared also; our conclusion, without that, would not be legitimate, seeing that γ is a function of p.

117. There should be no misunderstanding as to the signification of the expression (19); the weight of steam which escapes at each instant by a given orifice depends on its pressure at that instant, and consequently, the weight of air aspired equally depends on it.

For $h = 0$, for example, $Q_2 = 0$, because Q is so. The expression (18) indicates that for $h = 0$, x is nothing, and consequently Q, seeing that (14) gives then $w = 0$, which is besides self-evident. But for an equal value of Q, Q_2 is constant, whatever may be the pressure h, or its variations.

During one stroke of the piston, the pressure of the steam which escapes, and consequently the quantity discharged, vary at each instant; it is the same with regard to the quantity of air drawn in, which passes through the same phases as the first. But the total quantity of air aspired by a *given quantity of steam*, is independent of the pressure under which the latter escapes, and of the law which its variations follow; or at least, the specific weight γ_1 is alone influenced by these variations, and within very narrow limits.

118. *Effects of the variation of the jet of steam. Influence of the velocity of rotation.* But it is clear that in spite of the equality of the aspiratory powers, a jet of steam of very variable intensity is not, for the draught, equivalent to a constant and uniform one, giving, in the unit of time, the same mean quantity of steam. It certainly aspires in the unit of time, the same mean quantity of air, but under its influence, this air is sometimes in excess, sometimes insufficient. This is what takes place in an engine running, or rather rotating very slowly, to each puff of steam corresponds a puff of air, succeeded by almost complete stagnation of the draught. Thus this mode would in no way suit an engine with a single cylinder, and running at a very low normal speed. In locomotives, the variations in drawing in the air are reduced by the coupling together of the two engines at right angles, and by the rapidity of the rotation, that is to say, of the succession of strokes. In an engine with 5,90 ft wheels, going at a rate of 45 miles, that is to say making 3.54 revolutions a second, the jets of steam succeed each other at very small intervals, seeing that there are 4×3.54 of them $= 14.16$ per second.

Let us investigate this point more closely, anticipating for an instant the study of the distribution of the steam

At first, even if the engine were simple, the steam would be expended and consequently the air drawn in, in the course of one revolution of the wheels, in a very unequal manner without any doubt, but without any complete interruption, or only a very short interruption.

With the distribution by a slide, in effect, if there is no inside overlap, which is frequently the case in locomotives, as will be seen, the one of the two extreme ports is always in communication with the central port. At the instant when the slide attains the middle of its travel, the exhaust ceases for the steam driven back by the piston, but it commences on the other side, at the expense of the motor steam. There is thus continuity.

If there is inside lap, the exhaust ceases in front of the piston, when the slide has still to run over the distance of this lap to reach the middle of its travel, and it does not commence on the other side until the instant at which the slide has passed its mean position, by a distance equal also to this lap.

The exhaust is thus suspended altogether, at each stroke, while the slide runs through the double of the lap; and this interruption is very short because, on the one hand, the inside lap is always a very small fraction of the travel of the slide, and because on the other hand, the latter, runs through this very small fraction covering the port at its maximum velocity.

As long as the velocity of rotation is small, the steam which commences, on account of the lead, to escape before the end of a stroke, is discharged in great part, immediately at the commencement of the following stroke; from that point and as far as the beginning of the compression, the steam flies before the piston, exerting against the latter a back pressure nearly constant, and very slight, as will be seen. The irregularity of the draught is then very appreciable; at each beat the fire becomes brighter, and tends more or less to rise up bodily. The blast-pipe acts certainly, it is true, as a regulator, but its volume is insufficient; the irregularity and want of continuity of the draught thus come in to add to the reasons which, as has already been said, do not allow the velocity of translation of locomotives to go below a certain limit, except by giving up the direct connection of the pistons with the driving shaft (II, 199).

To this influence of the velocity on the draught is sometimes attributed the lowering of the pressure which is produced on going up inclines; but unless the velocity is not reduced too far, the primary cause of this lowering of the pressure, is not a reduction in the production of steam, from the want of draught. The latter keeps up at first, a little more unequal, it is true, but very active still, the more lengthened period of admission compensating

the smaller number of beats, and the blast being besides narrowed at need. If the pressure lowers, it is that the production, although great enough, greater indeed than on a level, is no longer able to balance the expenditure.

Thus the pressure and the velocity lower rapidly, and on a long gradient the train may be unable, with the assistance of its inertia, to reach the summit.

119. In stationary engines with *natural* draught (111), the fireman only affects the production of steam by stoking. The expenditure has no direct action on the production, and continued attention is necessary on the part of the fireman to maintain between these two elements, either equality, or at a given moment, any other determinate relation. In locomotives, as expression (19) indicates, the expenditure itself regulates the production.

On descending inclines, before and during stoppages, the closing of the regulator suppresses the draught almost entirely, and consequently the production. But that is only a particular and secondary case. During running, it is not the regulator, (109), but the lever, or better still the screw, which is the normal permanent instrument, by which the draught is regulated. If the resistance diminishes, the driver, reducing the period of admission, expends less steam, thus reduces the draught and consequently the production.

120. *Variable blast.* If in the expression (19, 116) we replace m and n by their values $\frac{F}{F}$, $\frac{F_2}{F}$ it becomes:

$$\frac{Q_2}{Q}=\frac{F_2}{F}\sqrt{\frac{\frac{F_1}{F}-1}{\frac{\gamma_2}{\gamma_1}\left(\frac{1+\chi}{2}\right)\frac{F_1^2}{F_2}+\frac{F_2^2}{F}}}=\sqrt{\frac{F_2^2\left(\frac{F_1}{F}-1\right)}{\frac{\gamma_2}{\gamma_1}\left(\frac{1+\chi}{2}\right)F_1^2+F_2^2}} \quad . \quad . \quad . \quad . \quad (20)$$

whence we see that F diminishing, Q_2 increases, everything else equal.

The increase of Q_2 reacts immediately on Q, that of Q in its turn, upon Q_2, but this double and reciprocal influence promptly reaches its limit, the combustion, and especially the heat gained by the boiler, soon ceasing to increase with the air drawn in.

There arrives a moment in which the gain of heat, due to a new increase of air, is equalled by the loss due to its cooling action. There is thus established, for the fresh blast orifice a new state of equilibrium. Thence, the rapidity of the effects, and the powerful action of the variable blast.

It serves to act at need, very promptly, in one direction or the other, on the production. It may equally serve to keep that constant, by making up

for the influence of the causes which tend to lower it temporarily; thus when the grate is charged, the resistance to the passage of the air increases, and a suitable reduction of the blast-opening, that is to say, a reduction of F_1 may balance the increase of χ, and maintain Q_2 nearly constant.

The substitution of coal for coke, and of large grates slightly charged, for the small grates heaped with a great thickness of fuel, has, without contradiction, reduced the utility of the blast with variable section. By taking advantage of favourable circumstances in the gradients of the line, and of the service of the trains, in order to charge and feed suitably, a careful driver easily arrives at being able to do without the variable blast, that is to say he leaves the orifice almost always wide open. Tried in England, the variable blast never came into use, even with coke, and in spite of the example of Stephenson, who applied it to several of his engines; while on the Continent, its use soon became general, and has remained so. This is because the English coals being more inflammable and more pure, only require a relatively weak blast; when the driver has occasion to act directly on it, he does so, in general, not to increase it, but on the contrary to moderate it, and he effects this by acting on the current at the other end, that is to say by the partial or total closing of the ash-pan (84).

The blast has also been made fixed on some of the Continental railways (II Pl. LXVI). Several engineers have thought that if the variation of the orifice can be dispensed with, it should disappear; that the driver, having at his disposal, a certain and energetic means of raising the pressure, is induced to neglect his fire, and thus led to make use of the variable blast, at the expense of economy, without valid reasons, and solely to make up for negligence. The fixed blast, applied some years ago to a certain number of engines on the Northern of France, and particularly to the *Crampton* engines, seemed to be favourable to economy, but without any formula being arrived at. However, on closer inspection, it was not thought proper to extend or prolong the experiment; and the variable blast which had been brought into question, was re-established. There seems in fact to be no possible doubt on this point. It is quite natural to suppress the variation of the blast, if it can never be of use. But if it can be useful in certain and even rare cases, to suppress it because a negligent driver would make use of it without necessity, is to prohibit it in order to prevent its abuse; and to do so would be a false principle, the application of which would lead to error. In the hands of a good driver, the variable blast is an instrument which increases the resources, and so to say, the elasticity of power of his engine; which permits him to overcome serious difficulties,

for example, when a bad lot of coal has to be run with; rapidly getting up again a pressure which has been reduced by any accidental cause, such as continued slipping, etc. The possibility of an unskilful or negligent driver ought to be foreseen, without doubt; but far from being an argument in favour of the suppression ot the variable blast, it is a condemnation. The less a driver presents in the way of personal guarantees, the less ought there to be taken from him, a means of action which his inattention or awkwardness may render so much the more necessary. While he would get out of his difficulty by the aid of the variable blast, and by burning, let us say, a little more coal, without such aid he would often break down. The fear of losing the premium for fuel is besides a sufficient guarantee against the abuse.

It would be wrong, especially at the present time, when traces of lines are becoming more and more difficult, to dispense with a simple although not indispensable organ, but useful to good drivers, and especially so to indifferent ones; no example ought to be followed blindly, not even the example of England; for my part, I do not hesitate to believe, that they would do well, on this point, to follow ours, and that they would find it to their advantage, if to return to the variable blast, which they have given up somewhat hastily.

121. *Moderation of the draught by reduction of the free section of the tubes* Dividing above and below, by F_2^2, the expression (20) becomes:

$$\frac{Q_2}{Q} = \sqrt{\frac{\frac{F_1}{F} - 1}{\frac{\gamma_2}{\gamma_1}\left(1 + \frac{\chi}{2}\right)\frac{F_1^2}{F_2^2} + 1}} \quad \ldots\ldots\ldots \quad (21)$$

The section F_2 of the tubes decreasing, Q_2 decreases also, if the other elements do not change, and, at the limit of F_2 or $n = 0$, Q_2 is nothing (19), which is evident. The draught can thus be reduced, not only by reducing the section of the blast-opening (up to a certain limit, still below the section of the port, and beyond which this increase would no longer have effect), but also by covering the orifices of a certain number of tubes in the smoke-box, a mode sometimes carried out in England, by means of louver plates, coming down in front of the tubes. The effect produced is complex, it is true, this reduction of the section of the tubes, suppressing the circulation of the gases through those which are stopped, paralyses their production, and reduces the heating surface; but we have seen (19) that the total evaporation may remain nearly constant, even when the one

half of the tubes was completely suppressed: the power of production of the other half being nearly doubled.

This fact proves that the section F_2 *can* be reduced, even by one half, without the value of Q, and consequently that of Q_2, being perceptibly modified. This apparent discord between observation and the expression (24), can only be explained by an increase in the numerator $\frac{F_1}{F} - 1$, making up for the increase in the denominator, and this compensation could not be established, in the experiment in question, excepting by the decrease of F, that is to say, by the reduction of the blast-opening: a reduction which ought to be the more marked, because with an equal value of Q_2 the coefficient χ increases when the section F_2 diminishes. In the absence of precise particulars as to the details of the experiments, the discussion cannot be carried farther.

122. *Moderation of the draught by the reduction of the amount of steam injected.* This is the method most naturally presenting itself, although it is, actually, the least used. By turning aside a part of the steam, before it passes into the exhaust, Q_2 is reduced in the same ratio as Q. Some engines, among others those of the *Berlin Société de Construction*, now receive a valve which permits the driver to send a portion of the steam leaving the cylinders, directly into the atmosphere; this is, by the way, only returning to a very old practice. Thirty years ago, on several engines, a tube was remarked inserted at the base of the blast-pipe, coming outside, through the bottom of the smoke-box, and provided with a cock.

"The means which it would seem ought to prevail", said in 1840, MM. *Flachat* and *Petiet*(*), "is the addition, at the lower part of the blast tube of a second exhaust passage taken from the first; this new passage which opens to the outside, under the cylinders, is provided with a cock, and when it is desired to diminish the draught, part of the steam is allowed to pass off through this passage."

If this addition was useful for coke, the only fuel used at that period, it would be still more so now with coal. It is true, that means of moderating the draught are not wanting, and if this one were applied, it would be natural to send the steam into the tender, in order to profit by its heat, at least within the limits compatible with the use of the injector (34).

123. *Numerical example.* The sole difficulty in the application of the formula (21) consists in the determination of the coefficient χ, which varies

(*) *Guide du mécanicien constructeur de locomotives*, 1st edition, 1840; 12 mo., page 61.

from one engine to the other, and in the same engine, with the charging of the fire, the nature and state of the fuel, etc.

Let us remark, at first, that this expression may be put in another form.

t_0 being the temperature of the external air, the pressure of which is p_0, and γ_2 the specific weight;

t'_2 the temperature of gases in the smoke-box, where the pressure is p_x and the specific weight γ_1, we have by Mariotte's and Gay-Lussac's laws:

$$\frac{\gamma_2}{\gamma_1} = \frac{p_0}{p_x} \cdot \frac{1 + \alpha t'_2}{1 + \alpha t_0}.$$

Now $\frac{p_0}{p_x}$ differs very little from 1, t_0 on the average is from 50° to 59°, while t'_2 reaches 662° and 762°. We may thus take without appreciable error

$$\frac{\gamma_2}{\gamma_1} = 1 + \alpha t'_2.$$

Putting $$\frac{(1 + \alpha t'_2)(1 + \chi)}{2} = \mu,$$

we have $$\frac{Q_2}{Q} = \sqrt{\frac{\frac{F_1}{F} - 1}{\mu \frac{F_1^2}{F_2^2} + 1}} = \sqrt{\frac{F_2^2 \left(\frac{F_1}{F} - 1\right)}{\mu F_1^2 + F_2^2}} \quad \ldots\ldots\ldots \quad (22)$$

If the determination of the factor $1 + \chi$ of μ, by the direct measure of the individual resistances which act on the current, is nearly impossible, we can at least obtain, in block, numerical values of this coefficient.

The above equation gives:

$$\mu = \left(\frac{F_2}{F_1}\right)^2 \left[\left(\frac{Q}{Q_2}\right)^2 \left(\frac{F_1}{F} - 1\right) - 1\right] \quad \ldots\ldots\ldots \quad (23)$$

and the value thus determined for a certain state of the engine, may be applied to other states thereof, not differing much from that. Supposing, with M. *Zeuner:*

That 1lb. of coal evaporates 6 lbs. 5, of water, and requires 240 cubic feet of air, whence

$$\frac{Q_2}{Q} = 2.30;$$

that the engine has 164 tubes 1 inch 65, inside diameter.

whence $$F_2 = 2.45 \text{ sq. ft.}$$

that F (mean section) = 0,147; and that F_1 (chimney of 1,03 ft.) = 0,83 sq. ft.

whence $$\frac{F_2}{F_1} = \frac{2.45}{0.83} = 2.95, \quad \frac{F_1}{F} = 5.65 \text{ (mean ratio)};$$

we have, by substituting in (23), $\mu = 24.60$

124. *Useful effect of the blast.* The weight Q of steam, which passes in the unit of time, through the opening F, with the velocity w, carries work with it : 1st, under the form of *vis viva* of mass ; 2nd, under the form of heat. The partial condensation of the free air being given up from the motives indicated, the utilizable work is only $\frac{Qw^2}{2g}$. The work utilized, that is to say, transmitted by the steam to the gases, is $\frac{Q_2}{2g} w_2^2$, w_2 being their velocity on leaving the tubes. The useful effect is thus

$$\eta = \frac{Q_2 w_2^2}{Q w^2},$$

or because of $$Q = F w \gamma_1, \quad Q_2 = F_2 w_2 \gamma_1, \quad \frac{F_2}{F} = n \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (116)$$

$$\eta = \frac{1}{n^2}\left(\frac{Q_2}{Q}\right)^3;$$

for $$\frac{Q_2}{Q} = 2{,}3 \quad \text{and} \quad n = 21{,}72 \quad \eta = 0{,}026.$$

According to M. *Zeuner* (*) we can also take as measure of the useful effect, under another form, the ratio of the work

$$\frac{(Q + Q_2)w^2}{2g},$$

carried off by the mixed current through the chimney, to the utilizable work $\frac{Qw^2}{2g}$; it is scarcely to be seen how this ratio can have the signification in question. If from the utilizable work be taken the work carried off by the mixed current, the difference is the work taken up for the draught, but of which the portion $\frac{Q, w^2}{2g}$ is alone utilized. The total work $\frac{Q}{2g} w^2$ is decomposed then as follows :

Work utilized : $\frac{Q_2 w_2^2}{2g}$,

Do. carried off by the mixed current : $\left(\frac{Q + Q_2}{2g}\right) w_1^2$;

Do. lost : $\frac{Q}{2g} w^2 - \frac{1}{2g} [Q_2 w_2 - (Q + Q_2) w_1^2]$.

In any case, under actual conditions, the question of the useful effect of the exhaust steam is troublesome. When the blast-opening is greater than the port, which the steam is obliged to pass through in order to escape, the back pressure on the piston is very nearly the same as if that port led directly into the atmosphere. Such is the situation at the present time,

(*) *Das Locomotiven Blas-Rohr*, page 229.

seeing that the engine runs with the orifice almost constantly full open, an attentive driver, and knowing his line well, having scarcely ever to keep his blast-opening smaller for any continued length of time.

In reality, with the locomotive such as it is, not condensing, the distribution done by slides with a large grate, and very thin layer of fuel, the draught, that strong breath which is the secret of its force, *costs nothing*.

True at this time, this effective gratuitousness of druaght by the exhaust was not so formerly, with the small fire-boxes, grates heaped up with hard coke, containing 12 and even to 18 per cent. of ashes, and the low pressures in the boiler. It was pretty generally admitted that the blast created a mean back pressure of $\frac{1}{3}$ atm. on the piston, and that the mean motive pressure hardly exceeded 2 atmospheres; whence it was conclud ed that the draught absorbed $\frac{1}{6}$ of the work applied to the pistons. The back pressure was considerable, in effect; but the error consisted in imputing it to the principle itself of the draught by the exhaust steam, while its real causes rested in the distribution, especially defective by reason of the great velocity of the pistons; it was on the one hand the running at a low degree of expansion, the too tardy beginning of the escape of the *motor* steam, and on the other the exaggeration of the resistances to the circulation of the air on account of the relative smallness of the fire-boxes.

A complaint against the blast was also believed to exist in the fact that the consumption of fuel per unit of weight of steam, is greater when it acts than when it does not. According to an experiment quoted by the *Engineer and Machinist's Assistant*, a locomotive evaporated a cubic foot of water: 1st. during running in 0.95 minute; 2nd. while standing, and consequently without the blast acting, 4.8 minutes. The blast thus increased the power of the boiler five fold; but also the consumption of coke, which, in the first case was 11.29 lbs. (or 6,46 lbs. of water evaporated per lb. of coke), was only in the second case 8.99 lbs., or 6.86 lbs. of water per lb. of coke, and further the proportion of liquid water was naturally less.

The draught by the blast, very favourable to the productive power, does not conduce to the economy of fuel. But this is simply the general condition of forced combustion and production. The rapid current determined by an energetic draught, passes off at a high temperature; a slow current has time to be robbed of its heat. But when, as in locomotives, an abundant production is the first condition, we are too happy to be able to realize it by a means gratuitous in itself, and at the price of an increase of consumption, which is the inevitable consequence arising from the very fact of the consumption being pushed very actively.

§ III. — Influence of various elements on the draught. — Experiments.

125. The whole apparatus of the draught comprises several elements, each of which has its portion of influence. This comes out of the preceding theory, which it was indispensable to set forth in spite of its imperfections, and which will gain without doubt in exactness and simplicity. The discussion of the expressions to which it leads, is so easy, that it is superfluous to dwell on it. Let us remark only, 1st., that for $m = 1$, the depression is nothing (18), as well as the volume of air aspired (19); which ought to be, for the chimney being then the continuation, at a very small distance, of the steam-pipe, the steam forms a cylindrical vein which fills it, without exerting on the air of the box any appreciable action; 2nd. that with an equal value of m, the depression and the volume of air aspired Q_2 diminishes when n increases, but that the first alone becomes nothing for $n = \infty$. The second has for limit $Q\sqrt{(m-1)\,h}$. This case of an infinite section of the air orifice F would be evidently realized by the suppression of the smoke-box, the chimney leading by both ends into the atmosphere.

Some engineers have endeavoured to determine the influence of the various elements by direct experiments. They cannot be passed over completely in silence. But to set forth and discuss all their results, to examine up to what point they agree, either with each other, or with theory, we should require to exceed the limits assigned to the extent of this chapter. Let us then confine ourselves to some essential points.

a: M. *Zeuner's experiments.* The apparatus (Pl. V, *fig.* 1) is composed essentially of a sheet iron chest C, into which penetrated a tube T communicating with a steam boiler, and provided with a cock, which allowed to vary the tension in the boiler up to 2 effective atmospheres. This tube, arranged so as to take different nozzles, turned up vertically along the axis of the chimneysw hich were adapted to an opening $m\ n$ arranged in the upper plate of the recipient. Another opening $p\ q$, variable at will, admitted the external air therein.

The experiment consisted in observing, once, the permanent state established, the depression $\frac{p_o - p_x}{r_o}$ in the recipient; it was given by two manometers, one with mercury, the other with water for the very slight differences. The steam jet was continuous, which simplified the apparatus; but, as we have seen (116), without modifying the power of aspiration of the vapour escaping.

125. 1st. *Influence of the volume of the smoke-box.* — M. *Zeuner* had a similar recipient constructed for preliminary trials, the volume being little more than the $\frac{1}{4}$ of the other. Now, all conditions being equal, that is to say, by applying to both large and small apparatus the same discharge opening for the steam, the same chimney and the same opening for admitting the air, the degree of rarefaction was the same also; from which we may conclude that the volume of the smoke-box is without influence on the depression established therein. It has probably two limits, the one above, the other below, which this volume must not exceed, but there is a great margin between them; so that the length of the cylindrical hoop which ordinarily forms the smoke-box (7) ought to be determined chiefly by conditions apart from the draught, for example, by that of a solid basis for the chimney.

This independence of the depression and of the volume is, moreover, not surprising. Let us suppose that at a given instant, the box contracts; if the aspiration of the steam, being exerted on a reduced volume, increases the rarefaction at first, this effect is almost immediately compensated, and the pressure re-established by the introduction into this reduced space, of a quantity of air constant, or very nearly independent of p_x (formula 19), aspired by a given quantity Q of steam. For the importance which some builders attach to the reduction of the volume of the smoke-box (7), there is thus no foundation, or at least only from the general point of view of lightness.

Further: it seems to us very probable, contrary to the general opinion, that a certain increase in the volume of the smoke-box would have positive advantages, from the point of view of the draught, effected, not as in the preceding experiment, by a constant steam jet, but as it is in reality, by a steam jet of very variable intensity.

To each state of the jet would correspond, according to the preceding experiment, a *final* depression, independently of the volume of the box, if this state were continued long enough; but, with this volume, the time necessary for the establishment of the depression, in the corresponding regime increases; the greater this volume, the nearer this value should be reached; the closer together the differences of the depression keep, the more consequently, the draught of air approaches uniformity. Like the blast pipe, the smoke-box, in a word, is truly a regulator of the draught; these two elements complete each other; if it be sought to increase the action of the first, the action of the second must not be neglected : to reduce it beyond measure being quite a fallacy.

126. 2nd. *Influence of the position of the blast-opening relatively to the chimney.* It was especially for the measure of this influence, that the small apparatus served, in which the chimney could be lowered more or less (Pl. V, *figs.* 2 to 6). Experiment showed that the distance *a b* may vary between pretty wide limits, without affecting the rarefaction, which of course is easy to comprehend.

If this distance is *nil*, and a *fortiori*, if it is negative, that is to say, if the blast-opening is let into the chimney (*fig.* 3), the depression diminishes, the section of the air passage, that is to say, the annular space comprised between the two openings, being too restricted.

The same thing happens if the distance *a b* is too great; the section of introduction of air into the chimney is the annular zone comprised between the lower edge of the chimney and the cone which the steam-jet forms in spreading out. This zone diminishes, and becomes even *nil* when the chimney, being raised, has its base placed on the surface of the cone (*fig.* 4). Beyond, the steam itself only partly penetrates into the chimney, the remainder being mixed with the air in the recipient (*fig.* 5).

127. 3rd. *Influence of the length of the chimney.* — In applying to the principal apparatus (125) chimneys of 4.92 feet, 3.70 feet, 2.46 feet, 1.23 feet; and 0.62 foot, M. *Zeuner* ascertained that this element may also vary considerably without the effect being modified. The minimum of the height appears to be about three times the diameter; the cone of steam then just grazes the upper base of the chimney; beyond (*fig.* 6), this cone ceases to fill the chimney; the external air comes in at α, β, and passes thence into the recipient.

The maximum of height is very great, and, not until it reaches about 30 times the diameter does the depression commence to decrease. Thus, with this mode of draught, the height of the chimney may vary in the ratio of 1 to 10 without the effect being perceptibly influenced. Between 3 and 30 times the diameter, the action proper of the steam being prolonged on the gases, certainly makes up for the increase of friction. Beyond that, the first has reached its limit, and the second alone continues to increase.

128. 4th. *Influence of the blast-openings, of the chimney, and the entrance-opening of the air.* — Within the limits of these experiments, the rarefaction does not depend on the absolute sizes of these sections, but only on their ratios (*); a result which is approximately in accord with expression (18) in

(*) *Zeuner. Das Locomotiven Blas-Rohr*, p. 42.

which the sections F, F_1, F_2, of the blast of the chimney, and of the air-opening, do not figure, but only the ratios $m = \frac{F_1}{F}$, $n = \frac{F_2}{F}$. Approximate accord, say we, for α' and β' are not at all constant; they vary with m, n.

The following are the results obtained, for the same pressure of steam, some with a mean value of F_2 ($d = 0{,}24$ inch), the others with $F_2 = 0$, that is to say the air-opening being closed:

Tableau A.

HEIGHT of the chimney.	EFFECTIVE PRESSURE OF THE STEAM IN THE BLAST PIPE. 1/4 atm.	1 atm.	2 atm.
	DEPRESSIONS $\frac{p_0 - p_x}{\gamma_0}$ IN INCHES OF MERCURY:		
	1st. Section of the air opening 2.36 inches diameter.		
feet			
4.92	0.090	0.322	0.602
3.70	0.102	0.342	0 614
2.46	0.090	0.327	0.622
1.23	0.094	0.315	0.472
0.62	0.047	0.185	0 236
	2nd. Section of the air opening *nil*.		
4 92	0.122	0.429	0.791
3.71	0.138	0.437	0.787
2 46	0.122	0.433	0.187
1.23	0.130	0.445	0.187
0.62	0.102	0.386	0.534

Diameter of the blast opening..... 0.39 inch
Do. do. chimney..... 3.94 "

The rarefaction effected in the closed capacity exceeds thus that which takes place in this capacity communicating with the outside by an opening of 2.36 inches, in a proportion less than would doubtless be supposed.

These figures bring out at the same time the influence *nil* of the greater or less height of the chimney, so long as this height exceeds three times the diameter; below that point the depression diminishes abruptly; thus, for a height (7.36 inches) a little less than double the diameter, it is reduced by nearly 50 per cent.

Let us further avail ourselves of the observations made with the apparatus when closed; the following table expresses the influence of the blast-opening:

Table B.

DIAMETER of the chimney.	EFFECTIVE PRESSURE OF THE EXHAUST STEAM (ATMOSPHERES). 1/4	1/2	3/4	1	1 1/4	1 1/2	1 3/4	2
	DEPRESSIONS IN INCHES OF MERCURY: Diameter of the blast-opening 3.94 inches.							
inches								
1.57	0.874	1.552	2.168	2.764	3.253	3 740	4.260	4.843
3.15	0.209	0.392	0.548	0.697	0.831	0.964	1.095	1.248
3.94	0.128	0.239	0.342	0.437	0.523	0.604	0.693	0.788
4.72	0.087	0.166	0.237	0.302	0.362	0.426	0.484	0.551
5.90	0.058	0.106	0.150	0.190	0.231	0.266	0.307	0.354
	Diameter of the blast-opening.							
1.57	1.760	2.905	3.842	4.843	5.946	7.402	7.965	"
3.15	0.420	0.742	1.043	1.354	1.630	1.942	2.228	
3.94	0.262	0.472	0.664	0.846	1.036	1.224	1.424	
4.72	0.180	0.315	0.457	0.587	0.718	0.858	0.992	
5.91	0.109	0.190	0.276	0.365	0.449	0.541	0.626	

The numbers of the second series are respectively nearly double those of the first; the two blast-openings being exactly in the ratio of 1 to 2, the depression, when all the other elements are constant, is proportional to the section of the opening and consequently to the expenditure of steam.

The aspiration in a closed vessel, does not present sufficient interest, from our actual point of view, for us to dwell further on it.

129. 5th. *Influence of the pressure of the steam.* — The depression $\frac{p_0 - p_x}{\gamma_0} = x - h$, which, according to the expression (18, 116), ought to be proportional to the effective pressure $h = \frac{p - p_0}{\gamma_0}$ in the blast pipe, certainly increases with that pressure, but not so rapidly, in the experiments the results of which the first part of table A reproduces under the head of example. But this proportion, obscured in the detail by deviations sometimes in one direction and sometimes in the other, re-appears when all the experiments are considered together.

Mr. *D. K. Clark* (*) had already observed this approximate law, and found, 1/14 for the mean value of the ratio in question.

130. 6th. *MM. Nozo's and Geoffroy's* (**) *experiments.*— The experiments of MM. *Nozo* and *Geoffroy*, which were made at nearly the same time as those of M. *Zeuner*, were carried out on the Northern of France, by means of a more complete apparatus, reproducing more exactly than the preceding one, the conditions of daily practice. The recipient received, not air from the atmosphere, but the hot gases from the smoke-box of a locomotive. An anemometer placed in the communication tube, gave the velocity of these gases directly, and consequently also, the weight of air aspired; the weight of the steam discharged was determined approximately, by calculation. The results, in their general features, agree pretty well with M. *Zeuner's*. However, they do not seem to confirm the fundamental law of the independence of the ratio $\frac{Q_2}{Q}$ and of the effective pressure h of the blast. This ratio would seem to diminish when the ratio increases. But the causes of error attending the mode of determining the weight of the steam, are sufficient without doubt, to explain the disagreement of which the following figures give an idea :

EFFECTIVE BACK PRESSURE in inches of mercury $\left(h=\frac{p-p_0}{\gamma_0}\right)$,	1.97	7.87	15.75	23.62
Ratio $\frac{Q_2}{Q}$	0.800	0.825	0.675	0.55
Do. F, F_2 and F_2 having other values	16.27	13.16	»	11.00

There is also a divergence with regard to some other points, particularly with reference to the length of the chimney, which would not seem to be indifferent, within such wide limits, and should not go below about 7 times the diameter.

Its section should be comprised between $\frac{1}{2,1}$ and $\frac{1}{2,4}$ of the total section of the tubes, and between 13 and 23 times the area of the blast-opening.

(*) *Railway Machinery*, page 224.

(**) *Expériences sur les conditions d'établissement des cheminées de locomotives.* (*Extract from the Mémoires de la Société des ingénieurs civils.*) Pamphlet in-8vo. *Lacroix. Paris*, 1864.

In the remarkable series of experiments which he made in 1864, on the power of production of boilers, the principal results of which have been reproduced (19, 121), M. *Geoffroy* observed also the correlative values of the depressions in the smoke-box, and of the volumes of air aspired, referred either to the fuel consumed, or to the time. By grouping the figures relating to the engine having all its tubes open (19), the following table has been drawn up :

Absolute pressure of the steam (average of all the lengths of the boiler) : 6.5 atm.

DEPRESSION in the smoke-box.	VOLUME OF AIR ASPIRED			
	COKE		BLOCK FUEL	
	per hour.	per lb. of fuel.	per hour.	per lb. of fuel.
Inches of water.	cubic feet.	cubic feet.	cubic feet.	cubic feet.
0.787	66,835	157.17	77,327	152.25
0.787	70,525	155.00	"	"
1.574	96,500	147.73	107,462	144.65
2.362	108,836	150.00	156,981	169.91
3.150	138,336	163.64	130,653	127.40
3.937	157,897	210.28	206,570	201.40
3.937	328,703	286.91	152,400	129.10

1st. The volume of air aspired in the unit of time increases then, every thing else being equal, with the depression, and nearly in proportion to its square root; which is in accordance with theory.

2nd. The depression has no influence, within the limits of the experiment (and excepting the figure of 287,73 c. ft, probably affected by some anomaly), on this volume referred to the amount of steam produced : which agrees equally with theory (116, formula 19).

131. 7th. *Influence of the shape; chimneys with curved and conical sections.* — M. *Prüssmann*, thinking that the form of the longitudinal section of the chimney might have a notable influence on the draught, and that the cylindrical form was far from being the best, endeavoured to construct a chimney with a rational section. The method of observation consisted in varying by successive trials, the diameter of the cross sections at different heights; that shape was adopted which corresponded, every thing else being equal, to the greatest depression in the smoke-box. M. *Prüssmann* obtained thus the shape represented in *fig.* 7, Pl. V.

The chimney with curved longitudinal section did not succeed. But the truncated cone shape, more easy to make, is pretty widely spread (examples:

II. Pl. XXI, XXII, LV and LXVI, etc.), and many engineers attribute a positive influence to it, without however agreeing either as to the position of the small base and the conicity, and without being in a position to define, in any precise manner, the advantages of the hollowed out form over the cylindrical one.

The section regarded as the best, is that which gives, everything else being the same, the greatest amount of depression in the smoke-box.

Thus is obtained (preceding table) the maximum amount of air in the unit of time, and consequently the maximum power of the engine, but not the maximum of air aspired, referred to the fuel consumed, and consequently to the steam produced.

If the advantages of this shape are positive, they should be definitively shown by an economy of fuel. But some estimates published on the subject of M. *Prüssmann's* chimney are exaggerated to such an extent that they cannot be taken seriously.

The question is to obtain, not the greatest possible depression, but a depression giving the necessary draught, with the minimum back-pressure on the piston, that is to say with the minimum of contraction of the blast-opening; and seeing that the back pressure due to the draught is very slight, almost nothing with the cylindrical chimney suitably arranged, what notable economy could be expected from any modification of its shape?

The advantages of the divergent chimney are thus doubtful; and if in certain cases it has been ascertained that its substitution for the cylindrical chimney really resulted in an economy of fuel, or in an increase in the power of the engine, the fact can hardly be attributed to anything but some faults of construction independent of the longitudinal section of the chimney, which were corrected at the same time.

By introducing into the formulæ which express the values of the ratio $\frac{p_o - p_x}{p - p_o}$ of the depression to the effective blast pressure, and to the ratio $\frac{Q_x}{Q}$ of the air aspired to the steam discharged, the condition of the hollowing out of the chimney, M. *Zeuner* (*) determined the degree of influence of this steam. The following is a numerical example: the ratio of the diameter at the summit being d_0, and that of the minimum section d_1, we have

for $\frac{d_0}{d_1} \equiv 1, \quad \frac{5}{4}, \quad \frac{3}{2}, \quad 2$

(*) *Ueber die Wirkung des Blas-Rohr-Apparates bei Locomotiven mit conisch-divergenter Esse.* — *Civil Ingenieur*, vol. XVII, 1871, p. 1.

$$\frac{p_0 - p_x}{p - p_0} = \frac{1}{14} \quad \frac{1}{11{,}70} \quad \frac{1}{10{,}88} \quad \frac{1}{10{,}37},$$

and

$$\frac{Q_2}{Q} = 2{,}291 \quad 2{,}498 \quad 2{,}582 \quad 2{,}640$$

This influence is thus very slight.

The ratio $\frac{d_0}{d_1} = 2$ is, in every case, that to which the maximum of effect very nearly corresponds. This would hardly however be reached by the adoption of a shape, indicated perhaps by the general facts of the flow of fluids, but the advantage of which are in no way prominent, if not exactly *nil*. It is true that the conical shape of itself raises no objection.

132. 8th. *Special chimneys for fuel producing many sparks.* — Fuels which are at the same time of small density, easily inflammable, and which break up easily in the fire, send into the smoke-box a considerable portion of incandescent particles, which the ordinary the smoke-box grating (84) cannot keep back. Such are wood, turf, and many lignites like those employed in Bohemia, in Southern Austria, and which are coming in general use on the railways in the North of Italy. A grate with the bars too close together would interfere greatly with the draught, and would require the blast to be much contracted. The carrying over of the incandescent particles into the chimney, is thus obliged to be suffered, and the latter is arranged in such a manner as to retain them, either altogether, or at least until they are completely extinguished. The first idea was to adapt to the top of the chimney, a wire gauze with fine meshes; but, even by widening and raising it so as to increase the outlet (II, Pl. LXXV, *fig.* 6), this top interfered with the draught still more than a similar grating placed in the smoke-box; which was naturally to be expected, the obstacle acting then not only on the gases, but also on the steam. Recourse was thus soon had, and is still in most cases, to Klein's chimney (Pl. V, *fig.* 8; and II, Pl. LIII, line from *Moscow* to *Kursk;* Pl. LXXI, old *Seraing* engine, Pl. LXXVII, *fig.* 1, *Engerth* engine of the Austrian State line; Pl. LXXVIII, *fig.* 13, *Camden* and *Amboy* engine, etc.).

The principle of this apparatus is that tried so often under different forms, and always without success (38), for preventing the water being carried over by steam, but the efficacy of which against sparks, if not complete, is at least nearly sufficient. Stopped in their progress by sheets of iron *o*, *o*, *o*, ... (*fig.* 8) which deviate the current, and on which they lose their velocity after one or two reflections, they fall down into the conical envelop K, K, which surrounds the chimney, become extinguished

therein, and a door allows them to be removed. The disadvantages of this chimney are the considerable hold which it presents to the wind, the increase of resistance to traction and the increase of strain on the smoke-box.

Klein's apparatus and all those, which like his (Pl. V, *fig.* 9, *Meyer; fig.* 10, *Thurmann; fig.* 11), are founded on *chicanes* opposed to the current which passes through the chimney, always interfere more or less with the draught. It is thus abandoned when not absolutely necessary, and replaced by the ordinary chimney with the grating in the smoke-box.

It was natural to expect that a notable improvement would be realized by acting, not on the whole mixed current of gas and steam, but only on that which it was required to purify, that is to say on the first, the second not being interfered with. Hence, M. *H. de Waldegg's* chimney, shown in *fig.* 12, Pl. V. But it does not carry out what it seemed to promise, as is easy to comprehend; for if the jet of steam is not attacked directly, the conical diaphram Q, by isolating it from the annular vein formed by the gases, interferes with the action of the steam on the air.

Without remedying the disadvantages of *Klein's* chimney, M. *Ressig* has at any rate simplified it; he surmounts the ordinary cylindrical chimney by a hood analogous to that of *Klein's*, and suppresses the envelope. The iron sheets must in this case have sufficiently large dimensions, in order that the sparks which escape, instead of accumulating between two sheets, only leave them after having had time to be extinguished.

133. *Remarks on the blast. Question of the unity or division of the jet of steam.*— The position of the blast-opening, relatively to the base of the chimney varies greatly; while, in certain engines this distance reaches 1,64 feet (II, Pl. XXI, *fig.* 1; *Krauss*), in others (*Orleans* Pl. XXXV and especially Western of France, (Pls. XXXIII and XXXIV) the blast penetrates far up into the chimney, even when not hollowed out at the base.

Whatever latitude there may in reality be on this point, it is probable that the limit is often exceeded, one way or the other.

The variable blast, generally used in France, is almost always of the type with *valves*, *v*, *v*, (II, Pl. XXVII, *fig.* 4; XXVIII; XXX; XXXIV; XXXV, XXXIX; XLI, *fig.* 1; XLIII; L; LVI, *fig.* 1). It has one disadvantage, and probably even two; the one most frequently complained of, but which is not serious, or rather not difficult to avoid, is that the derangement of a valve is sufficient to deviate the steam-jet from the vertical direction, and this greatly

interferes with its action; the other, probably the most serious, although an advantage has been, and perhaps is still alleged to be found in it, is that it does not divide the jet of steam.

It was not so formerly. In *Stephenson's* variable blast, since given up, the blast-opening was composed of two parts; the one constant, a central circle; the other variable, formed of a ring of openings, which could be more or less uncovered, or closed completely, by the rotation of an annular disc. Pl. LXXI, II, from the *Seraing*, offers a very old example of an equivalent arrangement; the circular discharge zone is continuous, and it is by the vertical movement of the hollow truncated cone M, N, that its breadth varies.

If, as is probable, the division of the steam into several jets, multiplying its points of contact with the air, is favourable to its action in carrying the air along, it would be suitable to apply it, particularly to the principal jet. This is what has already been done up to a certain point, in the blast with a *solid* conical stop, which is also very old, and used in Germany, where the apparatus with valves has not generally supplanted it, as in France. The steam-jet, full when the opening is at its maximum, becomes annular, and narrower and narrower, according as the stop is raised.

It would seem that the division of the steam into a sort of rose, giving it a better hold of the air, should be favourable to the carrying over of the latter.

The opinion contrary to the division of the jet was taken for granted, when the blast with valves was substituted for the old apparatus with a cone. Simpler than these, and preferable in this respect, it owed its success chiefly to the circumstance that it gives a single full jet, that is to say, according to all appearance, to a defect.

In the United States, the exhausts from the two cylinders are very often separated, as far as the opening; it is true however that this is on account of considerations partly unconnected with the division of the jet.

In a paper read recently at the Institution of Mechanical Engineers, Mr. *C. W. Siemens* brought forward an improved apparatus for driving air along by means of steam. The latter escaped through a very narrow annular orifice, and the air, at the same time, through the centre of this same orifice as well as through an outside concentric annular space (Pl. V, *fig.* 13). This arrangement of three concentric openings, multiplying the surfaces of contact between the steam jet and the two jets of air which envelop it, has been subjected to experiments which appear to have shown

its efficacy, that is to say, an increase in the quantity of air aspired by a given quantity of steam.

An application made to the production of rarefaction in one of the pneumatic tubes of the central telegraph station of *London*, led to this consequence, viz : that the same quantity of steam produces the same work, whether it acts thus directly upon the air, or whether it aspires it by the intermedium of a good engine and of a pump; so that the first method would greatly reduce the expenses of establishment and maintenance.

In the presence of these facts and of the success of the new form given to the blower with multiple jets (106), it seems indispensable that the question of the arrangement of the locomotive blast should be thoroughly revised, a question which has been defined, but not solved.

§ IV. — Heating of the feed-water by the condensation of the exhaust steam.

134. *Condensation of the steam.* — A great part of the heat produced is carried away by the exhaust steam and by the gases from the fire. It has been sought to recover a part of the heat for the advantage of the feed-water either from the steam, or from the gases, or even, though rarely, from both at once. In this latter case indeed, the water is put in connection with each of the currents, before their junction in the chimney. Sending the mixed current into the tender could scarcely be thought of, although sometimes tried : it requires the chimney to be very crooked, of excessive length, detrimental in itself to the draught, and all that only to force the gases to pass over the water, to which they would thus only yield an insignificant amount of heat.

Condensation, of which we have already spoken (93, 101, 112), but which it is desirable to examine more carefully, (the more so as it is necessary, as we shall see, to have recourse to it in certain particular cases, and for motives much more important than that of economy) is then restricted to a part of the steam turned aside before its injection into the chimney, and consequently not utilized for the draught.

Abstraction made of the mode of feeding, the two functions, draught and heating, are not incompatible, provided that the second be subordinate to the first, the latter continuing to absorb all the steam, when that is necessary, and only giving up to the other, that which may be taken without disadvantage; the application made during certain years in the North of Germany establishes the possibility of maintaining the temperature of the

tender in winter, nearly at the boiling point, without interfering with the draught.

M. *Kirchweger's apparatus.* Let us recall the principle of M. *Kirchweger's* apparatus, which was by far most generally adopted.

The blast-pipe from each of the cylinders is bifurcated (Pl. II, *fig.* 18); the two upper branches reunite in a vertical pipe T, the blast proper; the two lower branches finish in the horizontal tube O, the continuation of which, curved, plunges into the water of the tender.

Valves allow the steam to be directed either towards the blast, or towards the tender, or to divide them between these two directions.

This apparatus was the object of some trials made on the *Lyons* railway in 1854, which were prosecuted with considerable indifference, but were however, far from being without interest. After a certain period of guess-work, and as soon as the driver (engine 17) became familiar with the new instrument placed in his hands, economy seemed certain, and from 8 to 10 per cent. With the blast full open, the whole of the steam went that way; but by reducing its section to about 6 square inches, the current divided into two, and the tender-water rapidly heated. The carrying over of ashes and cinders into the smoke-box was much less than before the application of the apparatus; but this however may have arisen solely from the fact that the driver was then in the habit of running with the blast more contracted than was necessary. Lastly, the water, which by the way was good enough, got rid of a portion of its earthy salts in the tender. As to the difficulties of feeding, resulting from the high temperature of the water, in that case also they were completely surmounted by the addition of a small reservoir of air (*).

An objection, the increase of the back pressure on the pistons by the fact of the action of the apparatus, was raised at the very commencement, and it was afterwards admitted by some, and rejected by others, without one rightly knowing which to believe. It is probable, at the same time, that there were right and wrong on both sides, according to the case. It may easily be conceived in effect, without the necessity of dwelling on the point, that the apparatus may or may not increase the back pressure, according to the particular circumstances in which it works, according as the driver makes use of it more or less intelligently. This is what appears, in effect, to result from observations made on the Brunswick railways.

In order to contradict the alleged increase of back pressure, M. *Kirchweger*

(*) See the additions.

started on this observation : in many engines which had not been originally arranged expressly for the apparatus, the communication with the tender was made without changing the blast in any way; now, even when the latter was full open, the current of steam was always divided, says M. *Kirchweger*, between the two directions; whence he deduced this consequence, that the conduit, ending in the tender offered a less resistance than that of the blast. An evidently gratuitous conclusion. When a new issue is open to the current, it divides, but more or less unequally, according to the inequality of the resistances; and the fact of the division proves nothing as to the relative value of these latter. The fact appealed to is besides contrary to the observations made on the *Lyons* railway, although the diameter of the communication-tube was proportionally greater than in the German engines.

Taking everything into account besides, whether the condensation has or has not the effect of increasing the back pressure, is of little consequence. If under the same conditions, to do the same work, the engine consumes less by condensing, the economical side of the question is settled.

In Germany, the opinions were divided as to the amount of the economy, but almost unanimous as to the fact itself, at least as regards engines hauling heavy loads at a low speed, and running generally, consequently, with large admissions. The economy was then from 5 to 8 per cent, to keep to uncontested figures; as far as 15 and 18 per cent have been asserted, but it diminished, and even disappeared, for light and rapid trains, which probably arose from the requirements of a more active draught only allowing, altogether, a much smaller proportion of steam to be sent into the tender, and a much lower temperature maintained therein. With the bifurcation of the current, the contraction of the blast would in fact go directly counter to its aim; it would have the effect, not of increasing the draught, but, on the contrary, of reducing it, by forcing the greater part of the steam to take the other way. This contraction is only thus efficacious under the condition of intercepting all communication with the tender.

When running with the regulator closed, the blast ought to be open, if not, the aspiration of the pistons acts upon the water in the tender, and water may be absorbed. This accident occurred to an engine on which I happened to be once, between *Dresden* and *Görlitz*, and knocked off the head of the piston, but without smashing out the bottom of the cylinder; besides, in order to prevent it, a valve on the pipe communicating with the tender is sufficient.

It must be remarked, that by the sole fact of the substitution of the in-

jector for the pumps, which run with a vacuum when they are not feeding, a certain economy of fuel is realized, everything else being the same, of which the experiments cited give without any doubt a very exaggerated value, and that M. *Hennig* (*) estimates perhaps too high in carrying it to 5 per cent more and looking on it as nearly compensating for that which condensation effects.

To the economy of fuel more or less considerable was joined another, quite incidental, in general, and self evident; that of the water : seeing that there was only to make good the greater or less loss caused by the blast, and that caused by the chimney of the tender.

Another objection in principle, often raised *a priori* against condensation, is that it must affect the very power of the engine, because it disturbs the fundamental conditions of the draught. But, we have already stated, this condition, of the whole of the steam produced being devoted to the draught, is not absolute, not constantly necessary; it may be deviated from, provided that be suitably done. It is a matter concerning the driving of the engine.

Altogether, the most serious objection against condensation, as used in Germany, and as tried on the *Lyons* railway, is its incompatibility with *Giffard's* injector. However, by giving up carrying the water in the tender to the boiling point, and accepting as limit of heating, what the injector allows, about 104°, *Kirchweger's* apparatus would still produce an appreciable economy; but it is chiefly as a means of moderating the draught (122) that it appears to be often useful. Perhaps it was wrong to abandon it as well as to wish to extract the *whole* or *nothing* from it to the advantage of the feed-water.

135. *Heating the water on its way from the tender to the boiler.* — The condensation of the steam in the tender has been objected to because it prematurely heats the water, which radiates afterwards uselessly. It seems, in fact, more logical, to heat the water only at the moment when it is about to be forced into the boiler. In principle, the quantity of steam to devote to the same degree of heating would thus be reduced, or the heating due to the same quantity of steam increased.

But it is necessary to distinguish : if only bet condition laid down, is of heating the water in the open air, as soon as it is brought to and maintained

(*) Journal d'*Erkbam*, 1863, p. 305.

at 212°, that is all that can be required from the exhaust steam; all the excess of its heat is necessarily lost, and it matters little how, whether it be by the steam alone, or, partly, by the water which it has previously heated. The objection is thus only warranted, speaking economically, from two points of view: 1st, that of the engines in which, as was said just now (134), the limit of 212° cannot be reached, because the conditions of their work do not allow a sufficient quantity of steam to be withdrawn from the blast; 2nd, that of a more elevated limit of heating, the practical possibility being admitted of carrying the water, brought into contact with the steam at the very moment of its being forced into the boiler, up to a temperature above 212°.

This second principle has been tried on different occasions, particularly by Mr. *D. K. Clark*. The steam and the water forced in by a special pump, were brought together in a recipient B (Pl. II, *fig.* 13) into which the first was introduced by the tube *a*, and the second by the orifice *b*; it crossed the annular space and mixed with the steam jet. A second pump forced the mixture into the boiler. In other cases, the feed-water was forced through a worm tube placed in a case which received and condensed the exhaust steam.

The heating, by the waste steam, of the water pumped in on its way from the tender to the boiler has been the object of lengthened trials in Germany also. There the condensation was effected by metallic surfaces, instead of by simple mixing. In M. *Ehrhardt's* apparatus, the forced water passed through two bundles, each of twelve small tubes, enveloped by a case into which the steam was directed, when desired, by a tube branching out of the blast-pipe. In order to feed, the driver opened one of the pumps or both, and at the same time the valve placed at the bifurcation of the blast-pipe. The water condensed in the case ran down into the tender. The grease carried over by the steam was deposited, it is said, to a great extent in the case, whence its extraction is easy. This was one of the principal advantages attributed to this apparatus, the complication of which however, prevented its adoption. Its adoption more or less frequent, depended besides on the mode of feeding, whether intermittent, or continuous.

An arrangement analogous to Mr. *D. K. Clark*, and which zends to utilite at the same time a part of the heat of the gases, has lately been applied by Mr. *Bouch* to goods-engines on the *Stockton* and *Darlington* line (Pl. II, *fig.* 14). The hot water tank C, C, forms an annular envelope round the chimney, and is continued, widened out at D, over the smoke-box. The large pipe *t* which passes through the front part of the latter, and is enveloped by the hot gases, establishes a communication between the sym-

metrical sheets of water D, D. The pipe T, which brings in the water from the tender, ends in a ring m placed on the top of the tank, and pierced underneath with small holes through which the water runs in spray; it comes on to the plates p, p, equally pierced with holes, and mixes with the steam injected through two tubes θ, θ, branching off from the base of the blast-pipe, and turning up vertically into the tank.

Besides an injector, which can only play secondary a part in this case, on account of the elevated temperature to which the water must be brought when the apparatus is in action, the boiler has two pumps; the one on the right drives at will the water from the tender either into the boiler, or into the hot water tank; the left hand one, which drives the water heated in the tank into the boiler, can also, by the action of valves, feed the boiler directly with cold water.

With the exception of this attempt, which is but too recent for to be properly appreciated, the application of the exhaust steam to the heating of the feed water, after having worked regularly on a certain number of lines, is now almost abandoned. The elevation of the running pressure reduces its advantages, and its incompatibility, not however absolute, with the *Giffard* injector, gave it the finishing blow.

All agree besides that the engine should not be required to perform too many functions, which might interfere with its running, and in any case complicate its driving. On tihs account, in the numerous and varied trials of heating carriages, which have been made for several years, steam when required is taken, not from the engine, but from a special boiler set up in the luggage van. If indeed by exception, use is made of the boiler of the engine for the purpose, as was recently the case in France, on the *Charentes* line, it is not to utilize the exhaust steam, natural as that may at first seem : the steam being taken directly from the boiler.

136. *Suppression of the exhaust steam, and of the combustion, in certain tunnels.* — But there is one case in which it is certainly necessary to condense the steam, and to do still more: it is that of the railways with long tunnels and extremely numerous passenger trains, the type of which is the Metropolitan Railway of London. Into these covered ways neither exhaust steam, nor the products of combustion can be ejected. The one can be got rid of by condensing what is produced; the others, by producing none, or at least no notable quantity. The driver does everything in order to check the evaporation; the chimney has a hood, the ash-pan is closed.

In the open air, on the contrary, he sends the whole of the steam into the blast-pipe, contracting the opening by a conical stop to quicken the draught; in a word, he puts everything into operation in order to force the evaporation, and get up the pressure, which lowers in the underground portions, where the engine has to live, so to say, on itself. It is also in the open air that the driver gets up the fire, which he cannot do in the underground parts, because smoke would be produced and come out through the door; also because the access of cold air would increase the fall of pressure. Lastly, it is always in the open air that he feeds, from the same motive.

This intermittent production, sometimes nothing, sometimes forced, is, on the average, much less (hardly more than a third) than if the engines worked under ordinary conditions; it is, also, not very economical. It requires besides the engines to have a great excess of power, a large fire-box, so as to produce a great deal of steam very rapidly, and a great tractive effort, consequently possessing a great amount of adhesion, so as to be able to start very quickly (II, 211, 250).

The Metropolitan railway includes between *Moorgate* and *Bishop's Road*, that is to say on a length of about 5 miles, numerous tunnels, the longest of which exceeds 3,280 yards. At the outset, this run was trying enough to the officials and even to the passengers; the amount of the traffic, and consequently the weight of the trains having greatly exceeded expectations, the engines were too weak; they could not store up enough steam; it was necessary above all to get on, and in order to maintain a sufficient pressure, the driver could not help, sometimes, losing time, and pushing on his fire, even underground. And this seemed to be the more troublesome from the use of coke, which, if it does not give off smoke, is more subject than coal to produce the irrespirable, indeed poisonous oxide of carbon, (II, 371); and to the gases, steam was added on account of the insufficiency of the water tanks, and the consequent imperfect condensation.

In the first engines, the steam entered the water-tank by a tube A, ending in the cover (Pl. IV, *fig.* 15). The water heated rapidly on the surface, but the heat did not penetrate into its mass, and the steam was not long in escaping by the chimney of the tender. A volume of more than 100 cubic feet of water could not however be spread out in a thin layer; it was necessary then to heat the body of water. Immersing the steam tube to a certain extent was tried, but without success. The surface of contact between the water and the steam, was still too much reduced, the effect too slow,

and the steam had to overcome a pressure of water equal to the height immersed, in order to escape.

Two things are necessary : 1st, a surface of water as large as possible; 2nd, the renewal of that surface, that is to say, a circulation of water, a disturbance of equilibrium which insures the general heating of the mass *inversely*, that is to say by the upper layers.

This result has been attained by a very simple contrivance (*fig.* 15). Below the adductor tube A, always terminated in the cover, a vertical tube is suspended, a little less in diameter, open at the two ends, let in an inch or so into the first, and going down nearly to the bottom of the tank. The greater portion of the steam, escaping by the space α, α, spreads out as before over the surface of the water. But this surface is renewed, and acts efficiently until the complete heating of the whole mass, because the small quantity of steam which passes into the tube I is sufficient to set up a current.

Excepting in this detail, the apparatus applied to the Metropolitan engines is in every respect exactly M. *Kirchweger's*. It may therefore be asked why the difficulties encountered in *London* with the condensation of the steam, were not experienced in Germany, where it was sufficient to plunge the waste steam-pipe pierced with holes into the tender-water, to bring the temperature up to 212°. But between the two cases there is an essential difference; in the open air, the object was simply the heating of the water; in a tunnel it is the suppression of the steam by condensation. For the first, time was of little consequence; for the second, an immediate effect was required; the waste steam was no longer simply a loss, it was the very evil to be overcome.

At the present time, with more powerful engines having a thousand square feet of heating surface, weighing 42 tons, and drawing as much as 160 tons, the drawbacks have almost disappeared. It has even been possible to dispense with the brick arches of the fire-boxes which had been thus encumbered with the view of storing up heat. The pressure, limited hitherto, to 9 atmospheres (it is yet only by exception that it has been carried to 14 atmospheres, (47), does not go down below 6.4 atm. after the long run indicate where all is expenditure without production.

M. *Mayer*, engineer-in-chief of the Western of France, concluded from some experiments which he made on that line, on the occasion of the projects for underground railways in Paris, that the increase of power to which an increase of 10 tons in weight would correspond, would allow the Metropolitan engines to work for three or four miles with the production completely suspended.

For some time, at different points in the United States, at Chicago particularly, small locomotives have been working under analogous conditions, but pushed to the limit. During their run, from 3 to 4 miles, their production is not intermittent, but *nil*. These engines have neither fire-box, nor boiler, but a simple reservoir in which the work is stored up in the shape of water brought to a very high temperature, and consequently at a very high pressure. This is, with the advantages of a less volume, and the disadvantages of cooling, which by the way are easily diminished, the realization of the principle often proposed for compressed air, and was the object of trials which were soon given up, on the part of some engineers, and among them the illustrious *Sommeiller*.

As stated farther back, only coke, and of superior quality, is burnt on the Metropolitan; and this is because smoke is rigorously prohibited, in the open air as well as under ground.

Altogether, the difficulties that many people deemed almost insurmountable, even without foreseeing the enormous development of the traffic were not, in reality serious. There would always be at need, the resource of artificial ventilation to fall back upon, as at *Liverpool* (II, notes, page 862). But if it has been necessary to have recourse to this remedy, it is chiefly on account of the very troublesome circumstance of a steep gradient, and of the frequent slipping of goods engines, hauling heavy loads; it is thus in the tunnel, that the gases from the fire and the exhaust steam are given off in the greatest abundance. The conditions are thus quite different; and much more unfavourable than on the Metropolitan.

137. *Special measures for the Gower Street tunnel.* — If the atmosphere on this line is at times disagreable, experience proved at least, years ago, that its inconveniences had been greatly exaggerated. Even at the moment of the greatest activity of the traffic, and although the passage of the trains appears to have particularly the effect of mixng the gases on the spot, and also to be inefficient for ventilation, (which the relative smallness of the cross-section of the carriages and the superposition of the two movements in contrary directions explain), the proportion of the deleterious gases is, in reality, very slight. That of the oxide of carbon, of sulphurous acid is almost imperceptible; and the carbonic acid is far from reaching the amount found in theatres, even well ventilated, where great multitudes are collected.

The state of affairs is, however not yet considered quite satisfactory throughout, and the question is still being discussed. A particular circum-

stance recently allowed the passage of one of the most disagreeable sections of the whole line to be greatly improved, that from *Gower Street* to *Portland Road* (near *Regent's Park*) which presents a covered portion of 1,000 yards, above which passes, nearly at right angles, the great tube of the *Pneumatic Despatch Co.* This tube, 4 feet in diameter at the base, 4.5 in height and 3070 yards in length connects the *Euston* station with the pneumatic station in *Holborn*, the head quarters of the mechanical arrangements, and which is itself connected with the General Post Office. A steam engine works a fan 22 feet in diameter, acting alternately in one direction and in the other; blowing for the trains from *Holborn* to *Euston*, exhausting for the reciprocal trains, and keeping up a sufficient depression to take a waggon with letters and parcels, weighing about a ton, and carrying a shield fitting exactly the outline of the tube so as to form a piston. It will be at once seen how the working of the pneumatic tube in the direction from *Euston* to *Holborn* was able to be utilized for the ventilation of the Metropolitan tunnel. For that purpose it was sufficient (Pl. II, *fig.* 19) to establish a communication between them, by openings made in the roof of the second. These openings, (two rectangles 6 feet by 2 feet) are kept firmly closed by balanced swing doors, until the pneumatic train has passed the tunnel. Then by an automatic action these openings are uncovered, and the flap A at *Euston* closed, and the atmospheric pressure on the piston π is kept up by air rushing out of the tunnel S. On the return journey, as the fan is forcing, the doors fall over by themselves, intercept the communication, and the tunnel is of course not interfered with.

A notable improvement in the air is thus obtained at the very part where most required.

138. *Little Cessous line.* — The question occurred in France on a little line of 2.62 feet gauge, connecting the coal-mines of *Cessous* and *Trebiau* (Gard) to the direct line from *Paris* to *Nîmes*. As the engines enter into one of the headings of the mine, it was necessary, either to arrange the means of ventilation accordingly, or to act directly on the engine itself, in order to prevent the air from being vitiated by the emission of steam, and the gases of combustion. It is the second arrangement that was decided on, at least provisionally; two engines were designed and constructed by the Alsatian Society for Mechanical Constructions. *Figs* 16 and 17, Pl. II, taken from the drawings which the engineer of that Society, M. *Beugniot* has been good enough to communicate to me, indicate the arrangements made in order to carry this programme into effect, and

which, by the way, almost exactly reproduced those of the Metropolitan engines.

When the engine is acting under ordinary conditions, the steam passes into the chimney through E*e*, (*fig.* 17), passing over the valve *a* (*figs* 16 and 17). When in the mine, the driver lowers the hood *k* of the chimney, and at the same time, by means of the gearing *t m n p q* (*fig.* 16), he raises the valve *a*, which going home on its upper seat *xy*, closes the blast-pipe *e*. The steam, passing thus under the valve, at O, enters the tube $\theta\theta$, which turns up behind the admission tube *t*, and opening the clack *r* in the tank pipe A. Into this pipe enters, with the play $\alpha\alpha$, another pipe I going to the bottom of the tank, and pierced with holes at the lower part.

As soon as boiling point is reached, the large discharge valve *b*, which communicates by a tube τ (*fig.* 17) with each of the two tanks and is worked by hand by means of the wheel *m*, lets out the water, the tanks being immediately replenished.

Observation has shown that the working of the condensing apparatus involves no appreciable back pressure on the pistons (134).

The engine, with four wheels, weighs empty, six tons, and filled, with 200 gallons of water in the tanks, 7.77 tons.

CHAPTER IV

DISTRIBUTION OF THE STEAM.

§ I. — Distribution by slide without lead.

139. *Law of the velocities of the piston in uniform movement.* — To a uniform movement of translation of the engine, corresponds, for the piston connected with the driving-shaft by a crank and a connecting rod, an alternate rectilinear movement, the law of which can be determined analytically, or graphically. Let us dwell for an instant on this point.

1st. R being the length of the crank, B that of the connecting rod, x the variable distance from the small end of the connecting rod to the centre O, a distance equal to B — R at the beginning of the forward stroke, we have, when the shaft has turned through an angle α (Pl. V, *fig.* 14) :

$$B^2 = R^2 + x^2 + 2Rx\cos\alpha \quad \ldots\ldots\ldots\ldots \quad (1)$$

x and α are functions of the time.

Differentiating,

$$0 = x\frac{dx}{dt} + R\cos\alpha\frac{dx}{dt} - 2Rx\sin\alpha\frac{d\alpha}{dt};$$

or, $\frac{dx}{dt}$ being the velocity v of the piston at the end of the time t and $\frac{d\alpha}{dt}$ the angular velocity, supposed constant A,

$$0 = (x + R\cos\alpha)v - 2Rx\sin\alpha A \quad \ldots\ldots\ldots \quad (2)$$

(1) and (2) giving the values of x and v corresponding to the given angle α. By differentiating anew (2) we should have the acceleration $\frac{dv}{dt}$.

2nd. The velocity of the extremity M of the connecting rod is constant and equal to RA; that of the other extremity m, or of the piston, is thus $RA \times \frac{Sm}{SM}$, the point of meeting S of the normals to the trajectories at M and m being the instantaneous centre of rotation of the connecting rod.

For $\alpha = 90°$, this centre is at an infinite distance, $\frac{Sm}{SM} = 1$, the connecting

rod moves parallel to itself, and the velocity of the piston is RA, which is evident.

3rd. If the connecting rod is long enough relatively to the crank, we may take for the successive distances run through by the piston corresponding to equal angles, the differences of the versed sines (Pl. V, *fig.* 15); the corresponding distances run with a uniform velocity RA by the centre of the crank are the arcs 01, 12, 23... Taking on the vertical OP their corrected lengths, drawing through the points 1, 2, 3... vertical lines, and through the points 1′, 2′, 3′... horizontal lines, their intersections will give the points of the curve which has for abscissæ the distances travelled by the crank pin, and for ordinates those by the piston, reckoned from the commencement of the stroke. Drawing a tangent at any point M, the tangent of the angle β which this line forms with the axis of the x is :

$$\operatorname{tang}\beta = \frac{dy}{dx} = \frac{dy}{dt} : \frac{dx}{dt},$$

now $\frac{dy}{dt} = v$, $x = R\alpha$, whence $\frac{dx}{dt} = R\frac{d\alpha}{dt} = RA$,

and consequently : $v = RA \operatorname{tang}\beta$.

As we have $y = R(1 - \cos\alpha)$, $dy = R\sin\alpha d\alpha$,

$x = R\alpha$, $dx = Rd\alpha$,

$$\operatorname{tang}\beta = \frac{dy}{dx} = \sin\alpha.$$

The maximum of sin α is 1, that of tang β is thus equally 1 ($\beta = 45°$), and that of v is R.A and corresponds to $\alpha = 90°$, which is besides evident.

140. *Production of the alternate movement of the piston.* — In order to impart to the piston its alternate movement, the motor steam must press successively on each of its two faces, while the other communicates with the atmosphere. In order to shorten, we shall call : *motor face* that which receives the action of the steam, and *resisting face*, the opposite one; *forward stroke*, the stroke of the piston from left to right, and *back stroke* that from right to left.

To the cylinder is attached a box, q, q (Pl. V, *fig.* 16) in which ends the induction tube T and through which the steam rushes as long as the regulator is open. On the flat bottom of the box open, with rectangular orifices, three conduits; the two extreme ones ending at the extremities of the cylinder; the middle one passing round between the box and the cylinder, and finishing in the blast-pipe.

The steam which has acted on the piston, must, in order to get out of the

cylinder pass back through the same port; but it is necessary that in thus returning, it should find this port in communication with the atmosphere, by means of the central exhaust port. The latter is thus only in connection with the atmosphere and with one of the extreme conduits, sometimes one, sometimes the other, and these two conduits are always isolated the one from the other : at one end by the piston, at the other by the movable organ of the distribution, the slide.

The slide is a box turned upside down, applied by its edges on to the faces of the ports, and the external surface of which is pressed by the moving steam, while its hollow constantly covers the middle port, and alternately, each of the extreme ports. It can at once be seen what the dimensions and the movement of the slide should be, in order that it may fulfil its functions.

Let the piston, (*fig.* 16) be at the commencement of its forward stroke, and let us suppose at first that the steam is to be admitted during the whole stroke. The steam ought, during the whole of this time, to be rushing in through the port A, while that which has acted during the preceding stroke escapes through B. The slide, its edges being supposed without thickness, should thus, during the forward stroke, have the position 1, during the back stroke, the position 2, (*fig.* 17) and its travel would be equal to the common width of the two ports; it should pass, as rapidly as possible from one position to the other, at the moment at which the piston itself changes the direction of its movement; but the ports A and B would be in communication during the duration of the travel of the slide; and whatever may be the rapidity of this displacement, this departure of the fundamental condition of the separation of the admission and the exhaust is generally inadmissible.

In order that this may be got rid of, it is necessary and sufficient that the width of the edges of the slide be equal to that of the ports; and in order that the latter may be entirely uncovered for admission and for exhaust, the positions ought to be 1′ (*fig.* 18) and 2′ (*fig.* 19); that is to say, the travel ought to be the double of the common width l of the ports.

The slide could, in effect, pass thus rapidly from one extremity to the other of its travel, at the moment when the piston changes the direction of its stroke, and remain still all the rest of the time; but these abrupt changes of velocity of the organs are inadmissible in machinery with a very rapid rotatory movement, such as in locomotives. The travel of the slide ought to be gradually accelerated and retarded, running fast when it passes over the ports, and as it must not lose this velocity abruptly, it

ought to continue to move when it has passed over them, and consequently, in order to completely uncover them, to have a travel greater than $2l$.

The movement of the slide ought thus to be, rectilinear, alternate, gradually accelerated and retarded : in a word, exactly of the same nature as that of the piston ; and seeing that the latter imparts to the driving shaft a uniform movement of rotation, by means of a connecting rod and a crank, it is reciprocally, by an identical or equivalent mechanism, that the slide receives movement from the shaft.

The relative position to be given to the crank driven by the piston, and to the crank which drives the slide, results from what precedes. Abrupt changes of velocity being excluded, the slide ought to have taken, at the end of one stroke, the position suitable for the following stroke, or more properly speaking, the mean position between those, suitable to admission on both the faces; it ought thus to be at the middle of its travel, when the piston is at the end of its stroke.

The crank which drives it, or the radius r of the equivalent eccentric, ought thus to be keyed on at right angles to the line on which the slide oscillates. We shall suppose, which is the most frequent case, that this line is parallel to that about which the piston oscillates. If besides this were not so, if the first were inclined to the second at an angle a, it is clear that the radius of the eccentric would be involved in this movement, and the keying, would in that case have to be relatively to the crank, at $90° \mp a$, the sign — corresponding to the position (*fig.* 25, Pl. IV), and the sign + to the position (*fig.* 26).

In the hypothesis admitted, $a = 0$, the radius is keyed on at right angles to the driving crank. The slide thus covers the two ports, so that, instead of being full open when the stroke of the piston commences, the one for the admission, the other for the exhaust, they only allow at first the steam to enter and escape through very contracted openings; but the velocity of the slide being then at its maximum, the ports are uncovered before the piston, the starting movement of which is on the contrary very slow, has run through any notable portion of its stroke.

The centre of the eccentric will thus be (Pl. V, *fig.* 20) on the perpendicular aa' to OA, and at a distance r from the point O, that is to say at a or at a'.

That depends on two elements. The direction in which the shaft has to turn and the mode of transmission, direct or indirect, of the movement from the centre to the slide.

In the position indicated in (*fig.* 16), the piston can only travel from left to right; but to this movement, may correspond a rotation of the shaft, either in one direction, or the other. The slide, then in the middle of its travel, having to run at first in the same direction as the piston, in order that the steam may impart to the latter the only movement compatible with its connections, the centre of the eccentric should be placed accordingly, that is to say, in such a manner as to run in the same direction as the slide and the piston if the eccentric rod drives the slide directly, and in the contrary direction, if by the intermedium of a lever of the first order.

The centre will thus be :

If the transmission is direct :

In a for rotation in the direction of the upper arrow (forward motion);

In a' for rotation in direction of the lower arrow, (backward motion).

And if the transmission is indirect :

An a' for running forward, in a for running backward.

Whence this enunciation :

Rotation takes place, no other force than that of the steam coming into play, in a direction such that the radius of the eccentric precedes by 90° *the driving crank if the transmission is direct, and follows it by* 90° *if the transmission is ndirect.*

141. *Reversing the direction of running.* — It follows immediately from this, that, in order to run at will in one direction or in the other, a single centre is sufficient, and that the rotation is reversed by passing from direct transmission to indirect transmission, or reciprocally.

In running, reversing the rotation does not take place immediately, on account of the inertia of the masses in movement. Rotation continues at first in the same direction, the piston driving back before it the motor steam; then, the direction of the rotation changes; but it is not necessarily the same with the movement of translation, which persists during a certain time, if the mass, and the initial velocity of the train are considerable enough; the contrary rotation of the driving wheels thus brings in a retarding force equal to that which would result from fixing the wheels, the resisting work due to the rotation doing nothing more than balancing the work of the steam. So that this reversing of the rotation, from which very injurious slipping results, should be carefully avoided in practice.

The coexistence of the two contrary movements of translation and rota-

tion might even be indefinitely prolonged, under the action of an external accelerating force, that is to say, on an incline sufficiently steep, and this position is evidently more inadmissible still. But it is in treating of the means of stopping, that it will be desirable to study more closely the effects in question.

§ II. — Distribution by slide with lead and lap.

142. *Defects of the preceding method of distribution.* — This method of distribution, characterized by the keying on of the slide crank at an angle of 90° to that of the piston, and by the equality of the width of the edges of the slide and the ports, a method applied at the outset, is very defective, especially at a high speed.

The steam only exerts, in fact, on the motor face of the piston, its full pressure work, that is to say, out of its available work a portion which is so much the less the greater that pressure. It is put in communication with the cold source, when its temperature and pressure are still nearly those of the boiler, while that ought to be done only after its expansion to the external pressure. At the same time that the work applied by a given weight of steam on the motor face of the piston is much too small, the resisting work applied on the other face, by the steam that escapes, is much too great : the initial value of the back pressure being very nearly the same as that of the motor steam.

Serious as these imperfections were, attention was not first given to them, but to points of less importance; and it is in endeavouring to improve the latter, that, in a roundabout way, we have arrived at utilizing much more completely the heat of the steam, and regulating its expenditure according to the various conditions of the work to be produced, with the same pressure always in the boiler; and that by still retaining the same essential organ, the slide, while in no way is the machinery complicated.

It was remarked at first that the vertical position of the eccentric radius does not correspond exactly to the mean position of the slide, on account of the obliquity of the rod; we have in effect (Pl. V, *fig.* 21) b being its length :

$$BB' = BK - b(1 - \cos\beta) = r - b + \sqrt{b^2 - r^2},$$

$$B'B'' = r + b - \sqrt{b^2 - r^2}.$$

Thus, when the slide performs its complete travel $2r$, if the radius starts from the left horizontal position, (the eccentric centre, placed, relatively to

the axle, on the side opposite to the slide), the slide has not yet reached the middle of its travel when this radius is vertical.

It has gone beyond, on the contrary, by the same quantity $b - \sqrt{b^2 - r^2}$, if the radius has started from the opposite horizontal position (the eccentric centre placed, relatively to the axle, on the same side as the slide) (*).

At the commencement of the forward stroke of the piston, it is thus the port which should open for the exhaust which is open, for admission in the contrary direction by $b - \sqrt{b^2 - r^2}$ give while the opening of that which should give admission is similarly retarded.

This delay of the slide is enhanced by the *time lost*, that is to say, by the play at the joints, and by the bending of the parts. As the movement is propagated from the piston to the shaft, and then from the latter to the slide, it is desirable not only to correct this delay so that the admission on the motor face of the piston may begin at the very commencement of its stroke, but even to arrange that the port may be already uncovered at that moment by a small quantity; this is the *admission lead.*

In deviating thus from its mean position, the slide always supposed with edges of the same width as that of the ports, would give an exhaust lead equal to the admission lead. There must also in effect be an exhaust lead; it is even much more necessary, and ought to be much greater than the admission lead, and the greater, the faster the piston travels. The one side of the piston is pressed by the steam from the boiler, other by the steam admitted during the preceding stroke, and the work which it has gained at the end of its stroke is the difference of these two amounts. In engines rotating very slowly, the resisting work may be relatively small, although the exhaust port may not begin to open before the commencement of the stroke of the piston. As soon as the communication with the atmosphere is established, a very short time is sufficient to lower the pressure greatly, the more so, as the piston, then running slowly, reduces the volume slowly; the high values of the back pressure then correspond only to a small portion of the distance run by the piston, and consequently the work itself is small; but the more the movement of the piston is accelerated, the less the back pressure is reduced for the same pressure of the piston; the more the mean pressure, and consequently the work of the back pressure increase.

(*) The same fact, evidently for the piston, which is not at the middle of its stroke when the crank is vertical; by an amount, more or less, $B - \sqrt{B^2 - R^2}$.

The evil is reduced, if the slide already partly uncovers the exhaust port at the instant when the piston commences its stroke; the latter finds then, before having run through a notable fraction of its stroke, the pressure of the resisting steam already greatly reduced.

The admission lead ought to be very limited, as that is sufficient for the object to be attained, and by exaggerating it, the correlative fact would also be exaggerated, that is to say, contrary admission, towards the end of the stroke of the piston.

Now, in engines with a high piston-velocity, as in locomotives, the lead which must not be exceeded for admission, would be altogether insufficient for the exhaust. The latter has doubtless also a limit; if, on account of it, the counter pressure rapidly lowers, the motor work applied on the same face of the piston in the preceding stroke has diminished also, since the motor steam escapes into the atmosphere as soon as the exhaust port opens. Beyond a limit which can only be fixed by experiment, and which depends essentially on the velocity, more would thus be lost on one side than would be gained on the other.

We shall see later on, that the consideration of leads is not in reality so important as at first appears; the essential point being that they should not fail by deficiency; but let us not anticipate.

Let us suppose that at the usual velocity of the piston, the ports, 1.57 inch wide for example, should be uncovered, at the commencement of the stroke, by 0.20 inch for admission, and 0.98 inch for the exhaust. The linear lead of the slide will be the greater of these two figures.

The position of the eccentric sheaves is immediately deduced from this (Pl. V, *fig.* 22). The slide rod pin ought to be moved towards the right through $\alpha\alpha' = 0.98$ inch. The transmission being direct, from α' with the eccentric rod b as radius, an arc of a circle is described; its intersections a' and b' with the circumference described from the centre O and radius r, will be the new positions of the *forward* and *back* centres.

If the transmission is indirect, the pin of the lever, supposed with equal arms, has gone towards the left (*fig.* 23) by $\beta\beta' = 0.98$ inch; the arc described from β' with the rod for radius, will give at a'' the *forward* centre, and at b'' the *back* centre.

The angle ω is the *angular lead.* The sheave is keyed on in such a manner *that the eccentric radius* precedes *the driving crank by* $90° + \omega$, *if the transmission is direct, and follows it by* $90° - \omega$ *if the transmission is indirect.*

The linear lead BB′ (*fig.* 24) $= OB' - OB = r \sin \omega + b \cos \beta - \sqrt{b^2 - r^2}$,

and on account of $\sin\beta = \frac{r}{b}\cos\omega$, $BB' = r\sin\omega + \sqrt{b^2 - r^2\cos^2\omega} - \sqrt{b^2 - r^2}$ = nearly $r\sin\omega$, if b is great enough relatively to r. That is to say that the angular lead is then that which has for sine the lineal lead of the slide in the circle the radius of which is the eccentricity.

143. *Reversing.* — When the slide has a lead, the reversing can no longer be effected by simply passing from one transmission to the other; while changing the mode of transmission, the centre also has to be changed, seeing that it ought to be (Pl. V, *fig.* 25) :

With direct transmission..... { at *av. d* for forward running, / at *ar. d* for backward running.

With indirect transmission.... { at *av. i* for forward running, / at *av. i* for backward running.

To reverse the direction, by passing from one transmission to another, it would thus be necessary at the same time, to make the centre of *av.d* pass to *ar.i*, or *vice versa*, that is to say, to make the eccentric-radius turn through 2ω : while the same result is obtained, without changing the mode of transmission, by making the centre of *av.d* pass to *ar.d* (rotation $180 - 2\omega$) in one case, or, from *av.i* to *ar.i* (same rotation) in the other.

This displacement of the radius relatively to the crank, may be, and has, in effect, been produced by means of a single eccentric sheave, loose on the axle, and which a clutch allows to be fixed in any definite position at any moment. But for locomotives such clutches, which act with shocks, are quite unsuitable and quickly get out of order, while their effect is anything but safe at a high speed, even when they are in good order. It is far preferable to have one centre for each direction, that is to say one fixed eccentric, and consequently four in all. This is what has long been done.

The rule (140) is then modified thus :

The rotation takes place in a direction such that the eccentric radius precedes the crank by $90° + \omega$, *if the transmission is direct, and follows it by* $90° - \omega$, *if the transmission is indirect.*

144. *Displacement of the slide, corresponding to a stroke of the piston.* — Let us state a primary consequence of slide lead. When it is *nil*, the slide the travel of which is $2r$ resumes, at the end of one stroke of the piston, the position which it had at commencement thereof (Pl. V, *fig.* 26). With a lead ω (*fig.* 27), the same point in the slide takes, at the two extremities

of the stroke of the piston, two different positions, the distance between which is $BB' = OB - OB'$.

Now $$OB = r \sin \omega + b \cos \beta,$$

or, on account of $$r \cos \omega = b \sin \beta,$$

$$OB = r \sin \omega + \sqrt{b^2 - r^2 \cos^2 \omega},$$

in the same way $$OB' - KB' - KO = b \cos \beta' - r \sin \omega,$$

and on account of $$r \cos \omega = b \sin \beta',$$

$$OB' = \sqrt{b^2 - r^2 \cos^2 \omega} - r \sin \omega,$$

whence $$BB' = 2r \sin \omega,$$

a length which would only be equal to the stroke $2r$ if we had $\omega = 90°$, as is evident.

The consideration of this length BB′ is important in practice; we shall point out farther on (159) why.

145. *Approximate value of the velocity of the introduction of steam into the cylinder, the obliquities of the crank and of the eccentric rod being neglected.* — For a rotation α reckoned from the commencement of the forward stroke, the piston travels (*fig.* 28) $R(1 - \cos \alpha)$ and the slide

$$mn = r\,[\sin(\omega + \alpha) - \sin \omega] = 2r \sin \frac{\alpha}{2} \cos\left(\omega + \frac{\alpha}{2}\right).$$

v being the velocity of the introduction of the steam, at that instant, the volume introduced is $vdt \times$ the section uncovered of the port; calling k the admission lead, the width uncovered, always inferior, in practice, to the real width, as we shall soon see (148) is,

$$k + mn = k + 2r \sin \frac{\alpha}{2} \cos\left(\omega + \frac{\alpha}{2}\right),$$

l being the length of the port, the volume introduced during the time td is then :

$$vdtl\left[k + 2r \sin \frac{\alpha}{2} \cos\left(\omega + \frac{\alpha}{2}\right)\right] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The volume engendered during the same instant by the piston, of section S, is

$$S \cdot d[R(1 - \cos \alpha)] = SR \sin \alpha d\alpha \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

The volumes (1) and (2) are equal, whence

$$v = \frac{SR \sin \alpha}{l\left[k + 2r \sin \frac{\alpha}{2} \cos\left(\omega + \frac{\alpha}{2}\right)\right]} \frac{d\alpha}{dt} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$\frac{d\alpha}{dt}$ is the constant angular velocity A.

Distribution without lead. — If the admission lead k is *nil* which does not exclude slide lead, if there is outside lap (146),

$$v = \text{ASR}\,\frac{\sin\alpha}{2lr\sin\frac{\alpha}{2}\cos\left(\omega+\frac{\alpha}{2}\right)} = \frac{\text{ASR}\sin\frac{\alpha}{2}\cos\frac{\alpha}{2}}{2rl\sin\frac{\alpha}{2}\cos\left(\omega+\frac{\alpha}{2}\right)} = \frac{\text{ASR}\cos\frac{\alpha}{2}}{rl\cos\left(\omega+\frac{\alpha}{2}\right)}.$$

If there is no angular advance, $\omega = 0$, α disappears, and $v = \frac{\text{ASR}}{rl}$. The velocity being constant, the volume of steam introduced at each instant is proportional to the free section of the port; it also is so besides to the velocity of the piston; the section of the port is then at each moment proportional to that velocity. At the commencement, the velocity of the piston is *nil*, as is also the free section of the port, seeing that $mn = o$.

146. *Lap.* — *Outside lap; its consequences.* — Let us return to the slide taken as example (142). With its linear lead of 0.98 inch, it satisfies the condition laid down for the exhaust; but, for the admission, this lead ought to be reduced to 0.20 inch. Prolonging its outside edge by 0.98 inch — 0,20 inch is sufficient for this : this continuation e (*fig.* 29), being the outside lap.

This lap, which reconciles the two desired leads, has two consequences of main importance : on the side of the *motor* face, the expansion; on the side of the *resisting* face, the compression of the imprisoned steam.

a : Expansion. — The slide having, on account of the lead, passed beyond the middle of its travel at the moment when the piston commences its stroke, comes back before the piston is at half stroke, and returns to its initial position, then to the middle of its travel before the piston has terminated its stroke. It is between these two latter positions of the slide that the interesting fact occurs : in the first, the edge of the slide is no longer separated from the edge of the port excepting by the admission lead. As soon as it has travelled this small quantity, the port is shut, the steam confined in the cylinder expands, and this expansion lasts until the slide goes through a distance equal to the lap, that is to say, until it has reached the middle of its travel. Then the communication is established between the port and the atmosphere, and the steam no longer acts upon the piston excepting with a rapidly decreasing pressure; this is the effect of exhaust lead.

There is, with the distribution by slide, a strict dependence between the

circumstances of the distribution of the motive power on the one face, and the resisting work on the other. At first, the lap, by the fact that it involves the expansion on the one, combines with the exhaust lead to lower the initial value of the counter-pressure on the other. Afterwards, the exhaust port, already partly opened, at the moment when the piston commences its stroke, is completely uncovered (147) and remains in this state until the slide, having come back, has just reached its outside edge, draws gradually back, closes when the slide arrives at the middle of its travel, and remains closed while it travels through a length equal to the lap.

Beyond, the steam is admitted in the contrary direction; this is the effect of the small admission lead, the object of which is, as has been said, to insure in the following stroke, the admission at the commencement of the stroke of the piston, and not to form a cushion of steam for the purpose of destroying the velocity of the piston, to as to prevent a blow against the bottom of the cylinder. Such blow is impossible in rotatory engines, and it is necessary that it should be so since these engines often run without steam, but that which in ordinary running fills the space allowed between the piston at the end of its stroke and the bottom of the cylinder, which is useful nevertheless even from this point of view, since it diminishes the strain on the parts of the machinery, especially at the joints.

b : Compression. — While the exhaust-port is covered by the lap, the steam is compressed by the piston. This is the reciprocal fact of the expansion on the *motor* face.

It might be thought that the gain due to expansion is reduced by the whole of the existing work of the imprisoned steam on the other face; but the steam which filled the void space is not lost. If at the end of the compression, at the moment when the communication is established with the valve-chest, the steam in the void space was found to be brought by the compression to a tension equal to that of the motor-steam, there would be in proportion less to be supplied by the boiler. If then we assimilate the steam to a perfect spring, clearly the work employed to compress it, would be restored in the following stroke; it would be simply stored up. This compression would reduce by so much, it is true, the work acquired by the piston during its stroke, but by reducing also the steam expended; so that a suitable increase in the volume of the cylinder would be sufficient in order to neutralise this effect.

In reality, this is not quite how things take place, unless exceptionally. In general (and this applies to all distributions by slide), the steam compressed in front of the piston, does not reach the tension of the motor

steam, and the latter ought first, at the moment of introduction, to supply the complement by compression.

We shall return to this main fact of the compression, when we investigate the physical conditions of the work of the steam on the pistons. Here, it is a question especially of the geometrical conditions of the distribution of the steam. We shall thus confine ourselves to a single observation :

It is sometimes supposed, that if the amount of clearance be small enough, the tension of the compressed steam may be sufficient to lift the slide; and that, in accordance with the principle, that the compression cannot bring that steam up to a tension superior to what is in the boiler. But as there is a fall of pressure from the boiler to the valve-box, it is admitted in that case that the final tension of the compressed steam, while inferior to the pressure in the one, may be superior to the pressure in the other.

The fall, in any case, is small, and it attains its minimum when the regulator is about half open; and besides, in reasoning thus, the great inequality of the surfaces subjected to the contrary pressures acting on the slide, is not taken into account. The one acts over its whole surface, the other only on a portion equal to the length of the port. There is no question, certainly of bodily lifting up the slide; it would only *gape*, so to say, at one end, resting on the port face by the opposite edge, round which it would turn. But this very movement, in spite of the double leverage of the *under pressure*, supposes between the values per unit of surface of the opposite pressures, a disproportion which never exists in practice.

A great excess of pressure on the back of the slide-valve has been sometimes ascertained by diagrams taken from non-condensing engines, at low pressure, and working with an excessive amount of expansion. But the reason is, that this exaggeration would bring into play a peculiar circumstance to which we shall return shortly (148), as especially interesting to locomotives : the presence of air in the cylinder.

If, as the diagrams in question show, the pressure at the end of the expansion descends below that of the atmosphere, it is then not steam expanded beyond measure, which comes out when the port opens, but air which enters, and re-establishes the external pressure in the cylinder. The mixture of air and steam may thus, on account of the length of the period of compression, and the smallness of the clearance space, reach a pressure very superior to that of the steam in the valve-box. Thus is explained the abrupt rise in the curve, the ordinates of which are much greater, towards the end of the stroke, than those which correspond to the admission.

This very excess shows that, up to the end of the compression, the mixture of air and steam remains imprisoned, that the slide, in other terms, does not rise; at the same time, there is nothing impossible in this rise under such conditions; but they ought however never to occur, seeing that expansion pushed to this point is a fallacy.

147. *Trial of a large fixed amount of expansion by means of a lap. — Inside lap.* — These facts ascertained, it was natural to endeavour to use the property of the lap more largely. The question thus presented itself in a converse shape. The lap became the principal given quantity, it was taken, for example, almost equal to the port; e being its length, a the admission lead, the linear lead $a + e$ of the slide followed, as well as the angle of lead having for sine very nearly $r.\sin(a + e)$. But then a difficulty presented itself: the exhaust lead being also $a + e$, became, in its turn, excessive; according to the amount of e, the port was almost entirely uncovered at the very commencement of the stroke, or even the edge of the slide had already passed beyond the outside edge of the port (*fig.* 30). The object was thus exceeded.

Inside lap. — In order to bring back the exhaust lead to the desired amount ε, it was only necessary to do as had been done for the admission-lead, viz. to prolong the edge of the slide, but this time towards the inside, by a quantity i (*fig.* 30) equal to the excess of the total lead $a + e$ over the desired advance lap ε.

But the addition of this *inside lap* involves, for the distribution of the work on each of the two faces, analogous consequences to those of the outside lap.

On the one hand, the inside lap prolongs the period of expansion; instead of ceasing at the moment when the slide attained the middle of its travel, the expansion continues while this lap was travelled over. On the other hand, it prolongs also the period of compression, on the other face of the piston, of the imprisoned steam. When there is no inside lap, the period of compression commences just at the moment when the expansion ceases, they correspond to equal travels of the slide on each side of the centre, and consequently to equal lengths of time, and therefore also to different distances run by the piston, seeing that at the instant of the commencement of the expansion it has passed by the centre of its travel, and thus entered upon its decreasing velocity; it runs then a less distance during the second, that is to say, during the compression, than during the expansion.

With inside lap, the two periods of expansion on one face and compression on the other, instead of succeeding each other, partly occur together; they would commence and finish at the same time, if the inside lap went as far as to be equal to the outside lap, which is however inadmissible, seeing that the exhaust lead would then be simply equal to the admission lead.

A great amount of outside lap and an amount of inside lap equal to the corresponding lead of the valve over the exhaust lead, considered the most convenient, seemed, at first sight, a very happy combination; because the expansion can thus be commenced early, without however allowing the steam to escape too soon, and because at the same time the compression being confined to reducing the effective work per stroke of the piston, may be compensated by an increase in the volume of the cylinders.

It is in fact according to these principles that the distribution was arranged in the two engines of the *St. Germain* railway : the *Taylor*, and the *Gironde*. In the first, the ports are 1.50 inch, the outside lap 0.94 inch, the admission lead 0.24 inch, and consequently the total linear lead : 1.18 inch ; an inside lap of 0.51 inch reduced the exhaust lead to 1.18 — 0.51 inch = 0.66 inch. In the second, M. *Clapeyron* went farther still. In that case, with ports reduced to 1.18 inch, the laps 1.18 inch outside and 0.79 inch inside. The total lead was 1.38 inch and consequently, for the forward stroke the admission lead was 0.20 inch and the exhaust lead 0.60 inch. These leads were different for the return stroke, the slide being regulated for the symmetry, relatively to the ports, of its two *extreme* positions (159).

The disadvantages, and more than that, the impossibilities of this mode of distribution soon became evident.

148. *Disadvantages of this mode of distribution.* — 1st. Let us recall in the first place a point already alluded to : that with such variable work, and such frequent stopping and starting, the locomotive cannot admit of a large amount of fixed expansion. For a very considerable admission however, of $\frac{1}{2}$, to start by the simple opening of the regulator, would be impossible at the two dead points.

With the same engine, for low uniform speeds, and still more so for starting, a large admission is essential; at high speeds, a reduced admission. In other terms, a high degree of expansion is very useful in locomotives, but under the condition of being optional, and that, at need, admission may continue during the whole of the stroke, or nearly so.

2nd. A very great amount of outside lap, requiring as corrective, as we-

have just seen, an amount of inside lap as great as the former itself re-acts on the work which the movement of the slides absorbs, for it increases both their surface and their travel.

Opening of the ports, partial for admission, total for exhaust. — For the port to be entirely open for admission, and during an instant only, when the slide is at the extremity of its travel, the half of the latter (*fig.* 31) should be equal to $l + e$; but to increase the travel, is to increase the work absorbed by the movement of the slide, and the obliquity of the eccentric-rods; an obliquity which increases this work, with an equal travel, and especially interferes with the regularity of the distribution on the two faces of the piston, and is often excessive, even with reduced travel. It is thus that the half travel has always been made (or its equal, the radius of the eccentric r, when the transmission is direct) a length inferior to this length $(l + e)$, which seems however the extreme minimum. d being the difference, the maximum opening of the port to admission is $l - d$; the slide, at the end of its travel is still on the port, to the extent of d.

It may be asked, what is the use of giving this port a width l, which is not completely utilized; but it will be at once seen that if it is so for the admission, it is not so as regards the exhaust, and that on this side, the whole of the width l is utilized, that is to say (*fig.* 32) entirely open, for one instant only, if the inside lap i is equal to $e - d$, or (on account of $r = l + e - d$), to $r - l$ and during a finite time if this lap is smaller than that value. This is what always takes place. The ports are thus less widely open for admission than for the exhaust, but it is especially for the latter that large openings are necessary, in order to cause the back pressure to fall *rapidly*, and the disadvantage, which is slight however within certain limits, of contracting the admission ports, is accepted, rather than the greater one of an increase in the travel.

3rd. *Running without steam.* A large fixed amount of expansion by lap, inadmissible in locomotives, for the very sufficient reasons which we have pointed out, is further, incompatible with running with the regulator closed, which is a frequent occurrence with these engines, either for stoppages, or when running down gradients of moderate inclination.

At the moment of the closing of the regulator, which we shall suppose perfectly tight, the induction-pipe t and the steam-chest B (plate V, *fig.* 33) are filled with steam at the boiler pressure; but abstraction of this small quantity can be made, as it soon disappears, replaced by the gases from the smoke-box, which the piston drives in at each stroke, maintaining

therein an atmosphere more or less rarified. There evidently occur on the two faces of the piston, the following phases :

Motor face :

1. Aspiration of the steam, then of the gases by the valve-box.
2. Expansion of these imprisoned gases.
3. Aspiration of the gases from the smoke-box.

Resisting face :

1. Driving into the smoke-box, the gases which the piston has drawn in during its preceding stroke.
2. Compression of these gases, imprisoned *if the slide cannot rise.*
3. Driving these gases into the valve-box and into the induction-pipe.

The piston thus acts in expending work on the gases, that is to say as a brake.

This action in itself has nothing objectionable. On the contrary, seeing that the closing of the regulator, whether for the object of stopping, or of checking speed down inclines, always requires the intervention of retarding forces, and generally indeed very much greater than those in question. But its disadvantages are, on the one hand, the nature of the gases brought into the cylinder, on the other, the jerking motion caused to the slide during the period of compression (2′). Taken directly from outside, the air would be inoffensive in itself, but the hot gases drawn from the smoke-box carry over ashes and sparks, which cut into and rapidly wear the rubbing surfaces. To avoid this disadvantage, a clack-valve placed outside on the exhaust tube, was formerly tried on some of the engines of the *Lyon's* railway, allowing a direct communication to be established with the atmosphere; but we shall not dwell on this point further here, as it will come forward in counter-steam.

As to the other fact, in running with steam, the slide remains always set on the port-face, the moment, relatively to the opposite edge, of the under pressure on the edge of the slide, beinng uable to reach, by a long way, that of the pressure applied on its back by the motor steam (146). But with the regulator closed, the position is quite different. The slide is then only submitted externally to a very slight pressure, while the under-pressure increases from the commencement of the compression of the gases, the initial pressure of which is one atmosphere. If the period of compression is long, and the clearance space small, the pressure of the air may towards the end and even in this case, during the compression, be great

enough to determine the lifting of the slide. The air escapes then in bursts, making the slide jump, being simply guided by the frame which surrounds it.

The repetition of these shocks, would very soon cut into the polished surface, and put the motion out of order. In order to avoid these effects, in the *Gironde*, the compression of the air was limited, by increasing the clearance space to 0.2 cubic foot. But this *constant* reduced the ratio of the volumes of the steam at the end, and at the commencement of the expansion; the benefit of a great lap was thus lost, since it was introduced precisely with the view of a great degree of expansion. What is required, is that the period of compression should be greatly reduced when the engine runs without steam. It is necessary, on the other hand, that it should be able to run at need with a large admission, when the question is not of economizing the fuel, but of developing a great amount of work, and especially, as at starting, a considerable effort. The period of compression being so much the the less, the longer the admission, the question is solely, in the one case as in the other, so to arrange the slide with lap, as to produce a variable expansion. Thus, before closing the regulator, and so admitting the air, or rather the gases from the smoke-box, the driver takes a very simple precaution, he commences by putting the gearing into the position corresponding to the maximum admission, and consequently to the minimum compression, and the objectionable effects of the compression of the air during running are thus avoided.

The indicator-diagrams proved in effect, that in the *Gironde*, the aim had been overreached, abstraction made of the motives forabsolutely rejecting a notable amount of *fixed* expansion; and that the laps, and the clearance space, should have been much reduced, and the position of keying on the eccentrics modified in consequence. The inside lap especially, was excessive, and reduced the exhaust lead beyond measure. The inside lap must not be counted upon for producing expansion; that is the business of the outside lap, and the other, mostly nothing, and always very small, has only ordinarily the object of compensating in advance for a certain wear of the outside edges of the ports and of the slide, and to prevent the effects which would result from it, that is to say, a communication between the two ports, when the slide is at the middle of its travel.

In marine engines, this consequence is sometimes accepted systematically, and the hollow of the slide enlarged; the inside lap is thus *negative*. At the present time when the inside lap exceeds 0.08 or 0.12 inch, in locomotives, that is done as we shall see (168), for the purpose of correcting a fault,

the shortness of the eccentric rods; they present thus some examples of negative lap or space on the inside, but only when the distribution is effected by two slides (180).

The experiment made on the *Gironde* was very instructive, and very useful.

In his autographed conferences at the *École des Ponts et Chaussées*, M. *Clapeyron* pointed out in 1844, that " the principle of expansion by the lap had been known a very long time; that in 1805, *Watt* had already adopted it, but had kept its details secret, it being known only to some of his pupils; Watt besides gave the period of expansion very little extension. The principle of the arrangements adopted, " added M. *Clapeyron*, " has been set forth by M. *Reech*, in his memoir of 1836. " M. *Clapeyron* kept himself in the background here, with a modesty which enhances his merits, and is so much the more remarkable because it is not particularly common. If he has been anticipated in the study of the distribution of steam by the slide, no one has been the cause of more progress therein than he. What question has been taken up by this penetrating mind, without leaving in it some trace of progress?

Expansion by slide lap was introduced in 1838 on the *Liverpool* and *Manchester* railway, where the outside lap was carried from 0.126 inch to 0.38 inch, which, says Mr. *D. K. Clark* (*), " reduced the consumption by 25 per cent. and increased the speed. " The linear advance of the valve being also 0.38 inch, and the inside lap *nil*, the admission lead was *nil* also, (or more correctly speaking, there was a little delay) and the exhaust lead 0.38 inch. At the commencement of 1840, this lap was doubled (0.75 inches) and the consumption of the same trains went down 20 per cent, that is to say to 0.4 of its original amount.

In many English engines of average dimensions, the outside lap does not exceed 0.87 inch, and is ordinarily 0.67 inch for a complete travel of the slide equal to 3.9 or 4.3 inches. The whole tractive power of the engine may thus be taken advantage of, the admission for the maximum travel of the slide rising to 90 per cent. In the goods engines with large fire-box, of the Belgian State lines, the maximum admission, or for the full travel of the slide, is 76 per cent.

(*) *Railway Machinery* p. 24.

§ III. — Variable expansion by the slide valve with independent rods.

149. *Its principle.* — The expansion is effected while the admission port is covered by the excess of width of the edge of the slide, that is to say by the outside lap, if only one, by outside and inside laps, if both exist. The moderate outside lap, simply equal to the difference of the leads considered as normal, for exhaust and admission, has long been readopted.

The inside lap, the only reason for which in that case is the one we pointed out just now (148), is *nil*, or very small.

Figs. 1 to 4, Pl. VI, give the dimensions of the slides of engines of each of these categories : *Crampton*, passengers, mixed, goods, of the Mediterranean lines; the laps are respectively outside : 0.87 inch, 0.94 inch, 0.87 inch, 1.02 inch; and inside : 0.24 inch, 0.04 inch, 0.04 inch, 0.20 inch.

The expansion might be varied by varying the lap, but that would not be very practical; without taking into account that the increase of the lap would cause the small admission lead to disappear almost immediately, and would even change it into a delay, unless the angular advance were increased at the same time.

What is necessary in order that the expansion may be increased, is that, relatively to the progress of the piston, the admission port should commence to be covered sooner, and remain covered longer; now, in order to obtain this result with a constant lap, it is sufficient to reduce the travel of the slide, which will thus take longer to run over the lap.

It is very easy to carry this variation of the travel into effect.

Before the use of the different varieties of distribution by slide (150) became general, the two eccentric rods, for forward and backward running, were independent, when the one was in gear, the other connected to the system by the reversing pieces only, had no influence on the movement of the slide. In order to reverse, it was necessary, by means of the lever, to disengage the rod in gear, and put the other one into gear. This substitution had to be effected with certainty whatever might be the relative position in which the driver might find the parts of the mechanism; a condition fulfilled very simply by means of the forked arrangement of the ends of the rods (Pl. V, *fig.* 34). Provided that in all the positions of the system, the valve-rod pin always continues to project vertically between the appendages p, p, of that one of the rods which is free (which is very easy to verify by a diagram), the exchange is evidently always possible

The rod which the driver raises or lowers, as the case may be, in order to put it into gear, at the same time that by the same movement, he puts the other out of gear, necessarily brings on to the driving pin one or other of its appendages, which forces it to slide along this inclined plane to take its position in the notch.

In this system, which is now given up, the variation of the expansion, that is to say, of the travel of the slide, is founded on the use of an indirect transmission, and on the variation of the ratio of the leverages.

Such is the common principle of *Sharp* and *Roberts*, and of *Cabry's* expansion gear. In the one, (*fig.* 35), it is the arm driving the valve-rod, which varies, in the other (*fig.* 36, and Pl. VI, *fig.* 5), it is the arm driven by the eccentric rod. The variable arms form a slide K in which the driver, by means of a weigh-shaft, puts into gear more or less, in one case, the driving arm of the valve-rod; in the other, the extremity itself of the eccentric rod *b*. It is evident that in the latter case this bar is terminated by a pin, and that it is the groove of the lever which is forked.

In the first case (*fig.* 35), the inclination given to the lever by the angular lead is not modified by the play of the gearing; and the link being straight, the more the rod *t* is brought down in order to diminish the travel, the more the slide runs towards the left. The admission-lead thus diminishes; it might even, if the expansion were desired to be pushed too far, be changed into a delay, a point which ought never to be reached.

The same thing takes place as regards the second arrangement (*fig.* 36). As the pin of the eccentric rod is removed from the bottom in order to diminish the amplitude of the oscillation of the lever, and consequently the travel of the valve, the lever approaches the vertical, and the valve is again brought towards the left.

The lead would increase, on the contrary, (*fig.* 37), if, in the second case, the positions of the link and of the valve were changed one for the other.

We shall see that this disturbance of the lead in one direction or in the other, affects also those gearings most in use now; while others, which are exempt from it, are not on that account appreciably superior. The constancy of the leads for all degrees of admission is thus, in reality, of secondary importance; its influence disappears, as we shall see by numerical examples (175), before that of the other elements of the distribution.

It would be superfluous to dwell on expansion gears with independent eccentric rods. The one applied in England, the other in Belgium, have both long disappeared, in favour of link-motions.

§ IV. — Distribution by rods connected by a link.

150. *Stephenson's link.* — The two eccentric rods are connected by a circular link formed either of a single piece, or of two pieces bolted together, taking the pin which drives the slide rod.

The most usual form of this mechanism (Pl. V, *fig.* 38), is that which bears the name of *Stephenson;* its character is, that reversing and varying the expansion, are obtained by raising or lowering, by means of a rod jointed on to the link, the latter itself and the eccentric rods.

The maximum admission, either in forward or backward gear, corresponds evidently to the position at the end of the link, applied, either on the side of the forward rod, or on the side of the backward rod, against the sliding pin which transmits the movement to the valve. With the double link, or that formed by two pieces, taking between them the pin block (Pl. V, *fig.* 39 and II, Pl. XXX), the very end of each of the rods can be lowered or raised up to the latter. Thus, the movement of the valve is due solely to the action of this rod; the other takes no part in it, just as in the distribution with independent rods.

With the simple link (*fig.* 40), no longer taken sideways by the joints of the bars, but at its extremities O, even when at the bottom of its travel, the movement of the link is determined mainly by the predominating action of the neighbouring rod, and also to a certain extent, by the other. But this fact does not constitute a serious inferiority in the simple link jointed at the ends, for even with the double link, the total travel is never given to the valve, neither consequently the maximum value of the admission. It is sufficient, moreover, in order to come within the conditions of the double link in this respect, to bring the joints of the eccentric rods, as in that case, towards the middle of the link; and as with the simple form there is only the hinder face free, it is on that (*fig.* 41) that the joints O O′ are placed; they thus cease to be on the axis of the link, a circumstance which has, like all the other elements of this articulated system, its influence on the travel of the valve. This form of simple link is extensively used (II, Pls. XLIX; LXI; LXXI; LXXVII).

Dead point of the link. — Between the upper end of the link and its middle M, gives *forward gear*, with admission more and more reduced. Between the middle and the lower end, gives *backward gear*, with admission more and more prolonged.

When the link is placed in its mean position, with the stud at its centre (*fig.* 42), the valve-motion is said to be at the *dead point;* but the position is very different to that which corresponds, with independent rods, to the putting one or other of them in and out of gear. The slide-valve, immovable in this second case, when the engine is running by acquired velocity, or down an incline, is not so in the first. It would be so if there were no lead; but with the angular advance, even when one is equal to the other, the horizontal projections of the arcs described by the front and back centres, when the axle turns through a certain angle, are different; the contrary distances run through by the extremities A, B, of the link, are not equal, and consequently its middle is not immovable. Not only, has the slide still a very small travel to run through, but it uncovers a little of the ports, and still allows a small amount of admission (151).

The immovability of the slides at the dead point is easily effected : by widening out the link at the middle. An example of this is shown by fig. 6, Pl. VI, which represents a valve-motion with a single eccentric (172). The link is much widened out at the middle portion, in such a way that it can only give large admissions, in either forward or backward gear. The same peculiarity existed in some engines on the *Rouen* line, but in that case the link was only widened out for a short length. This form, which rendered the making of the link more difficult, and interfered both with its action and its working by means of the lever, is completely given up.

The *dead point*, properly so called, that is to say the point of passing from one gear to the other, does not correspond to what is called the dead point of the lifting lever, viz. to the mean position of the bolt, or of the index, if the working is done by a screw. The determination of this point is neither so simple nor so evident as is ordinarily believed. We shall however investigate this subject when treating of counter-steam.

The rod for lifting the link is sometimes jointed on to its centre M (*fig.* 38), sometimes on to its lower end, sometimes, but more rarely, on to its upper end (II, Pls. XXV and XXXIII); double links are now also made, the suspending pins of which are neither at the end, nor at the middle. The second mode has the advantage of giving a longer suspension-rod in the same circumstances, a point to which we shall return when discussing the distribution (164).

Let us notice also the two different arrangements applied to the stud, which is sometimes on an oscillating lever, transmitting the movement to the valve-rod by the intermedium of a jointed rod (II, Pls. XXXIII;

XLI; XLIII, *fig.* 1), sometimes to the continuation of the valve-rod itself, working in guides (II, Pls. XXX; XXXIX; XLVI, *fig.* 1, LXI).

151 *Direct rods, reversed rods.* — We have supposed (*figs.* 38 and 42), the link jointed by its upper extremity, with the forward eccentric rod. The reverse arrangement (*fig.* 43) is applied equally. In the first case, the bars are said to be straigth (or *open*); in the second, reversed (or *shut*); terms which only apply to the position indicated, that is to say to the commencement of the direct stroke of the piston, for it is evident that in the second arrangement as well as in the first, the rods cross and uncross, in the course of one complete revolution.

For *Stephenson's* link, as for independent rods (149), the lead of the valve varies with its travel. If the rods are *direct*, the lead increases with the expansion, and diminishes if the bars are *reversed* (167). It follows thence that, the fixed lead, under the same circumstances, that is to say of the valve at its maximum travel, and consequently the angle at which the sheave is keyed on, should not be the same for the two systems. It is desirable that they should be greater in the case of reversed rod, so as not to become insufficient for the degrees of expansion in ordinary running.

When the link is brought over towards the dead point, the lead increasing if the rods are straight, the valve uncovers the ports more and more; but if the engine were running near the limit, or the dead point, the valve would close the admission port almost immediately, on account of the smallness of its travel, the extremity of which it has very nearly or even altogether reached. With the rods reversed, the lead diminishes as the link approaches the dead point, and may disappear, or even form a retardation.

Of course, instead of driving the valve directly, the link may act on it by the intermedium of a lever of the first order; the sheaves are therefore keyed on accordingly (143). This complication is however, avoided as much as possible, by placing the valve vertically, with its rod in the horizontal plane of the axis of the shaft; and it is sufficient; when the valve is placed, not on the side, but on the top of the cylinder, to incline the face of the ports, in such a manner that its plane passes through the axis of the driving shaft.

152. *Gooch's link.* — This very simple arrangement goes away with the variation of the lead: the link (Pl. V, *fig.* 44, and II, Pl. XXXVII, *figs.* 4 to 6; Pl. LX, *figs.* 4 and 5) suspended by the middle to a fixed point F, drives the valve by the intermedium of a rod *t*, upon which the weigh-shaft acts.

When this rod is taken by the centre of the link, the valve-motion is said to be at the *dead point.*

It is clear that this link, like the preceding one, admits of two arrangements of the rods : direct and reversed. In the first case, the forward gear, at the different degrees of expansion, still corresponds very nearly (150) to the upper half, and the backward gear to the lower half of the link. It is the reverse which takes place in the second case.

What we have before said, as to the dead point, applies equally in this case.

The amplitude of the travel of the pin in the link, diminishes with the admission. Two types of the *Orleans* engines gave the following results :

1st. *Passenger engines. Gooch's link, straight rods.*

Ports 1.38 inch. — Lap..... { Outside..... 1.38 inch
Inside..... 0.24 »

EXPANSION NOTCHES.	1	2	3	4	5	6	7	8	9	10
FORWARD GEAR.										
Relative movement of the pin.....	inch 0.47	inch 0.43	inch 0.39	inch 0.35	inch 0.31	inch 0.28	inch 0.28	inch 0.24	inch 0.20	inch 0.12
BACKWARD GEAR.										
Relative movement of the pin.....	0.79	0.55	0.39	0.31	0.20	0.12	0.08	"	"	"

2nd. *Goods engines. Same slide, Gooch's link, rods crossed.*

FORWARD GEAR.										
Relative movement of the pin.....	0.55	0.47	0.39	0.31	0.24	0.20	0.16	0.12	"	"
BACKWARD GEAR.										
Relative movementof the pin.....	0.55	0.51	0.39	0.35	0.12	0.24	"	"	"	"

We have not hitherto spoken of the radius of the link. We shall see, in the discussion on the distribution (162), how this element is determined in *Stephenson's* valve-motion; but, in the actual case, if the condition is laid down of the constancy of the leads for all degrees of expansion, we see at once that it is fulfilled by a link having the form of an arc, with the centre at *o*, the point where the rod *t* is jointed on to the valve-rod. The latter remains immovable, whatever be the position given to the rod *t*; in other terms, the lead is constant. This form moreover satisfies the other es-

sential conditions of the distribution quite as well as the preceding one. The constancy of the leads (a theoretical constancy, for there are often notable disturbances, on account of the play between the parts), is only a small advantage. *Gooch's* link presents another one : in order to reverse the direction of running, or only to change the expansion, all that is required is to displace a simple rod, and not in this case the whole system of rods and link together. Although more positive, this second advantage is of no greater value, the rods and the link of *Stephenson's* valve-motion being equilibrated, and the resistance arising mainly from the valve itself; the reduction of the masses, and consequently of the forces of inertia, is however of some importance ; an importance which at the same time is less, since the substitution of the screw for the lever allows the reversing to be done with certainty, and without danger to the driver. Altogether, the grounds of preference in favour of the reversed or *Gooch's* link are not very serious ; it is in fact, and rightly, much less used than the preceding one. In order that it may give a regular distribution of the steam, the eccentric rods and the bar *t* must be long enough, otherwise the influence of their obliquity becomes too perceptible. *Stephenson's* link is thus preferable when there is only a short distance between the centre of the eccentric and the valve, as is almost always the case in locomotives, the second axle of which is the driving one (examples of application : II, Pls. XXIII, *fig.* 4; XXXV, *figs.* 4 to 6; LV; LVIII; LX, *figs.* 4 and 5, etc.).

" The link is a stroke of genius " says Mr. *D. K. Clark* (*), and he is right. According to him, it was first pointed out by Mr. *Williams* (**), but in a defective form, happily modified by Mr. *Howe*, who gave it the form applied by *Robert Stephenson* in 1843 (***), (rods direct, suspended below). At the same time, according to Mr. *D. K. Clark*, *Gooch's* link dates from the same year (****). This latter form was applied in 1845 to engines of the old Rhone and Loire railway, by M. *Bousson*, who was led to it, in endeavouring to avoid the variations of the leads involved by *Stephenson's* link. There appears to be no doubt that M. *Bousson*, on his part, did invent this modification, if, as would result from the dates given by Mr. *D. K. Clark*, he did not invent it *first*.

153. *Allan's or Trick's link.* — The characteristic feature of this valve-

(*) *Railway Machinery*, p. 26.
(**) Do. do. do
(***) Do. do. p. 27.
(****) Do. do. p. 49.

motion is the straight form of the link, thus escaping the pretended difficulties of manufacture presented by the curved or circular link. This assertion, often repeated as an argument in favour of the straight link, is not very important. That the link works under unfavourable conditions, that it wears rapidly, although case hardened, is quite true, whatever may be its form. But where then, in what shops have difficulties been ascertained to arise from the circular form of this piece ?

However that may be, the inventors of this modification (*fig.* 45), introduced nearly at the same time, in England by *Allan*, and in Germany by *Trick*, have succeeded in obtaining, with the straight link, a distribution practically equivalent to that of *Gooch's* link, including the constancy, not in this case rigorous, but approximate, of the lead of the valve. The parts are those of *Gooch's* motion (whence results, as in that case, the necessity of a great enough distance between the axes), but the variation of the expansion and reversing are obtained by combining the two movements belonging, the one to *Stephenson's*, the other to *Gooch's* link, that is to say the displacement of the link, and of the valve-rod.

The mechanism is not thus so simple as in the two preceding cases: this is in general a fault; but in the actual case, the introduction of one or two elements more may be of use, if new means of correcting the defects of the distribution result from it, provided these do not render the mechanism more delicate, and more subject to get out of order. (Examples of application ; II, Pls. XXI, XXIV, XLVIII, LXXX, *fig.* 3 ; LXXXII, *fig.* 8.)

154. *Influence of the suspension springs on the distribution.* — Locomotives are subjected to a special influence which intervenes in the very delicate conditions of the distribution, and interferes more or less with it. In stationary engines, the cylinders are invariably arranged with relation to the driving shaft. In locomotives, the cylinders are supported by the suspension springs, the play of which, notwithstanding their stiffness, exerts an action, which is in no way to be neglected, on the positions of the valve relatively to the ports, especially if the eccentric rods are short, and if the state of the road involves a large amplitude to the oscillations of the springs.

Engines with an intermediate driving shaft (II, 251, and II, Pl. XX, *figs.* 2 and 3, F, F) placed on the frame-plates, the position of which, relatively to the cylinders being on that account invariable, escape this disturbance, which sufficiently explains the considerable differences in consumption, sometimes found in engines of the same series, completely identical in appearance, and differing only in the flexibility and adjustment

of the suspension springs. But the intermediate shaft is not a solution. It is only a question, after all, of an imperfection of detail, and the remedy cannot be purchased at such a cost.

The same may be said, and with far greater reason, of the arrangement adopted by M. *Carels*, a Belgian builder, (175), which consists in transmitting the movement of each piston to the driving wheel of the same side by an oscillating lever, having its axis of rotation on the frame.

Such means are out of proportion to the result, and if it should seem useful to get rid of the disturbance in question, that must be effected by the combination of the organs themselves of the valve-motion. As we shall see farther on (174), Mr. *Stewart* succeeded in this; but there again, the remedy is without doubt worse than the evil, although in a less degree.

Let us add that the anomalies remarked between engines of the same type occasionally arise in part, from a cause already stated, of the same order as that now occupying us. If the boiler has not sufficient freedom, its longitudinal expansion and contraction, and also the changes of form of its cross section under the pressure, react on the frame, and put the pieces of machinery out. Thus the erection, unequally affected by the action of the boiler, may produce effects similar to those of the cause we are treating of.

§ V. — Discussion of valve-motions with a single slide and independent rods.

155. Notwithstanding the simplicity of the meandism of valve-motions with a single slide, it is chiefly in an empirical manner, by tentative methods, that the values of its different elements are determined, and by experiment, that they are verified.

The true *criterion* is, definitively, the consumption of fuel referred to the work done, adding thereto, however, a main condition particularly for locomotives, simplicity and ease of maintenance.

In order to study the details of a valve-motion, use is often made in workshops of a light model usually to scale, mounted on a board, and the elements of which : angles of advance, lengths of the eccentric rods, point of fixing and manner of suspending the link, etc., can be varied by means of a pressure screw, suitably placed. These apparatus are convenient for trials, but, like diagrams, they can only give the fraction of the stroke of the piston corresponding to each of the three phases of the work applied

to each of the two faces and the corresponding opening of the admission and exhaust ports.

Calculations, very simple, provided some terms are neglected which often in fact can be so, have the advantage of bringing out the influence of certain elements, and give useful indications for the direction, and the importance of the modifications which it is desirable to make in them in order to improve a motion.

Distances run through by the piston, and by the slide, for an angle of rotation α *reckoned from the commencement of the direct stroke.* — 1st. R being the length of the crank, B that of the connecting rod, α the angle of rotation, the distance x run through by the piston is (Pl. V, *fig.* 46) :

$$x = MM' = R(1 - \cos\alpha) - B(1 - \cos\beta),$$

and on accout of

$$R \sin\alpha = B \sin\beta,$$

we have

$$\cos\beta = \frac{1}{B}\sqrt{B^2 - R^2 \sin^2\alpha},$$

$$x = R(1 - \cos\alpha) - B\left(1 - \sqrt{1 - \frac{R^2}{B^2}\sin^2\alpha}\right) \quad \ldots\ldots\ldots \quad (1)$$

2nd. r being always the eccentricity, b the length of the rod, ω the angle of advance, we have for the travel y of the slide (*fig.* 47) :

$$y = cc' = oc' - oc = oD + Dc' - oE - Ec.$$

Now

$$oD = r \sin(\omega + \alpha),$$

$$Dc' = b\cos\beta', \text{ and because of } b \sin\beta' = r\cos(\omega + \alpha),$$

we have

$$\cos\beta' = \frac{1}{b}\sqrt{b^2 - r^2\cos^2(\omega + \alpha)},$$

$$Dc' = \sqrt{b^2 - r^2\cos^2(\omega + \alpha)}.$$

Besides

$$oE = r \sin\omega,$$

$$Ec = \sqrt{b^2 - r^2\cos^2\omega}, \text{ carrying forward :}$$

$$y = r[\sin(\omega + \alpha) - \sin\omega] - b\left(\sqrt{1 - \frac{r^2}{b^2}\cos^2\omega} - \sqrt{1 - \frac{r^2}{b^2}\cos^2(\omega + \alpha)}\right),$$

an expression which could also be deduced from that (1) of x and y replacing R by r, B by b, α by $\frac{\pi}{2} + \omega + \alpha$, and subtracting from the result the value which it takes for $\alpha = 0$, that is to say, the distance of the slide from the left hand extremity of its travel, at the moment when the piston commences its stroke.

Working the radicals out, and taking only the two first terms :

$$y = r[\sin(\omega + \alpha) - \sin\omega] + \frac{r^2}{2b}[\cos^2\omega - \cos^2(\omega + \alpha)]. \quad . \quad . \quad . \quad . \quad . \quad (2)$$

If R is small enough against B, and r small enough against b, for us to be able to neglect $\frac{R^2}{B^2}$ and $\frac{r^2}{b^2}$ before 1, we have :

$$x = R(1 - \cos\alpha). \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$y = r[\sin(\omega + \alpha) - \sin\omega] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

values which are fixed at once, remarking that in the hypothesis of a connecting-rod and of a valve-rod of infinite length (Pl. V, *fig.* 28), the piston runs through the versed sine of and the slide the difference mn of the sines of the angles $\omega + \alpha$ and ω.

By eliminating α between (1) and (2), we have for the equation of the curve of which x and y are the distances along the rectangular coordinates :

$$R^2y^2 + r^2x^2 + 2Rr\sin\omega \,.\, xy - 2Rr^2\cos^2\omega \,.\, x = 0.$$

This is the equation of an ellipse, the centre of which is at the origin. For $\omega = 0$ it becomes : $R^2y^2 + r^2x^2 - 2Rr^2.x = 0$. The y axis is thus the major axis of the ellipse.

In locomotives, the ratios of the connecting rod to the crank, and of the valve-rod to the radius of the eccentric, are rarely great enough for the approximate values (3) and (4) of x and y, to be made use of. Instead of calculating the exact values, they are determined graphically. The two semi-circumferences AMB, *amb*, (*fig.* 48) described simultaneously, the one by the crank-pin, the other by the centre of the eccentric, being divided into the same number of equal parts, a series of circular arcs is described from the points of division 0, 1, 2.... with the connecting rod, and from the points 0′, 1′, 2′.... with the valve-rod for radius. The distances of the points of intersection of these arcs with the axis Ox give the relative distances run through, 0′1′; 1′2′; 2′3′....; of the piston, and 0″1″; 1″2″; 2″3″.... of the slide.

156. *Tracing the ellipse of the slide.* — The oldest graphic method and one still much used consists in drawing, by means of these value taken for rectangular coordinates, the curve named, by extension, the *ellipse of the slide*, or *egg-shaped curve*, the manner in which this runs being shown by *fig.* 49, Pl. V.

The inclination $\frac{dy}{dx}$ of each element of the curve on the x axis, measures the ratio of the simultaneous velocities $\frac{dy}{dt}$, $\frac{dx}{dt}$ of the slide and of the piston. At the origin, at A, the velocity of the piston is *nil;* that of the slide is finite, the tangent of the inclination of the first element of the curve is thus infinite; the curve takes off normally to the x axis.

The velocity of the piston increases; that of the slide, which on account of the lead, has passed over the middle of its travel, diminishes, the ratio $\frac{dy}{dx}$ decreases : the curve is concave toward the x axis. The slide attains the extremity of its travel before the piston is at the middle of its stroke. It is thus to an abscissa Aa less than the half stroke, that the point corresponds for which $\frac{dy}{dx}$ is *nil*, that is to say the horizontal element.

Beyond that, the slide coming back, the ordinates diminish. The slide returns to its initial position when the piston is at N, a position for which the ordinate is *nil*, as at A. Farther on still, the slide deviates from its initial position in the contrary direction; the ordinates are negative. The slide is at the middle of its travel when the piston has run through AS corresponding to the ordinate Aμ = the semi-travel of the slide diminished by aM. At the moment the piston arrives at the end of its stroke, its velocity is *nil*, $\frac{dy}{dx}$ is infinite, the last element of the curve is vertical.

For the return stroke, starting from A′ and taking the abscissæ from right to left, a curve A′M′A′ is produced similar, but not identical, on account of the obliquities of the rods, to the first, which it has closed in at A.

When the question is, not of discussing a project, but of examining and rectifying the distribution of an engine, it is desirable to take directly from the engine itself the correlative positions of the piston and the slide. The engine being cold, and the front-end of the cylinder as well as the cover of the valve-box being removed, the driving shaft is turned by pinch-bar through small successive angles, and the distances of the piston and the slide from their respective initial positions are measured. The advantage of this proceeding is that it approximates as much as possible to reality; the play at the joints is taken into account, and only the small elastic deformations are eft out of the parts under the action of the strains developed by the pressure of the steam, as well as the expansion of the parts subjected to an elevated temperature.

The complete curve is contained in a rectangle, to the sides of which it is tangent, and which has the stroke of the piston for base, for height the travel of the slide. The second is ordinarily represented on a larger scale, in order to increase the lengths to be measured in that direction. The curve, less flattened, gives at the same time less elongated intersections.

157. *Use of the curve* (Pl. V, *fig.* 49). *Direct stroke.* — The curve gives the positions of the slide relatively to the piston ; but its positions relatively to the ports, depend on the position given to the port-face with reference to the axle, or, in other terms, on the *regulation of the slide* (159).

1st. If it be wished to make the axis of the central port coincide with the axis of the slide at the middle of the travel, μ being the centre of CD, Aμ is the lead of the slide and consequently, the quantity by which the admission port would be uncovered at the origin of the stroke, if there were no outside lap.

Carrying this lap from μ to o, oA is the admission lead. The slide uncovers the port more and more, until it has arrived at the extremity of its travel, and consequently the piston is at a. If, starting from o, a length $o\alpha$ is taken equal to the width of the port, the point α is always above C, that is to say that the port is never entirely uncovered during the admission (148); but it is so and remains so a certain time during the exhaust; so that the whole of its width is thus utilized, and in the most important event.

The admission port, which commences to close again when the piston is at a, is completely covered when the piston arrives at b, and it remains in that state while the slide runs through the sum of the laps, that is to say μk being the inside lap, until the piston is at d; bd is thus the distance run through during the expansion. Beyond, the communication with the atmosphere is established, and the exhaust commences.

The stroke of the piston is then divided thus, as to the three events of the work applied on its *motor* face : 1st, admission from a to B; 2nd, expansion from b to d; 3rd, anticipated exhaust from d to B. The length of each of the periods : exhaust, compression, back-pressure on the opposite face is obtained in the same manner.

In considering the lower half A'M'A of the curve, we should have exactly in the same way the distribution of the work on each of the faces of the piston during the return stroke.

2nd. If it be desired to regulate the slide in such a way that the axis of the face of the ports should coincide with the middle of the interval between

the positions of the middle of the slide, which correspond to the two dead points of the piston, the parallel drawn through the middle of the length AB′, must be substituted for the line $\mu\mu$. Then the slide, in the middle of its travel, is no longer placed quite symmetrically with reference to the ports (159).

158. *M. Zeuner's trace.* — The trace of the *ellipse of the slide* has one drawback, its length. There are several other methods which are much more expeditious, as they do not require, like the preceding one, the trace of a curve by points. Such particularly is M. *Zeuner's* method. But it supposes the rods to be infinitely long, a hypothesis admissible for most stationary engines, but rarely for locomotives. This is sufficient to justify the preference given in railway workshops, to the preceding method. It is desirable however that the second should be equally adopted; being sufficient for engines with a long wheel-base, it gives for the others, and particularly for the new valve-motions, a very convenient mode of succinctly studying their general arrangements.

Let us take up again the approximate expression (4) (155) $y = r\,[\sin(\omega + \alpha) - \sin\omega]$ of the deviations of the slide relatively to the position which it occupies at the origin of the stroke of the piston. If it be wished to refer the positions of the slide, not to this initial position, but to its mean position, $r \sin\omega$ must be evidently added to y, being the distance between its initial and mean positions (144) : this gives $e = r \sin(\omega + \alpha)$.

In order to construct this value, we draw (Pl. V, *fig.* 50) a line Ox. Through a point O we take Oy perpendicular to Ox, a straight line Oz making with Oy the angle of lead ω, we take $OM = r$, and on this diameter we describe a circumference; it is easy to see that a chord OP, making the angle α with Ox, measures the deviation of the slide, corresponding to a rotation α of the driving shaft. For in the triangle OPM, right angled at P, we have :

$$OP = r \cos O = r \sin(\omega + \alpha).$$

Discussion. — (*Fig.* 1, Pl. VIII, reproduces the trace on a large enough scale for its details to be easily followed out.) At the dead point $\alpha = 0$, we have $e = OP_1 = r \sin\omega$; this is the linear advance, the rod being supposed of infinite length.

e is *nil* for $e = 180 - \omega$; and in effect the chord is then reduced to the tangent OP_3. The slide is in its mean position. For $\alpha = 180$, $e = -r \sin\omega$, a value equal and contrary to that which corresponds to $\alpha = \omega$, and which can be taken on Ox, to the left of O. There would thus be a second circle,

tangent to the first at O, but the consideration of which is not necessary, seeing that it is only a question of absolute values. e is a maximum for $\cos(\omega + \alpha) = 0$, or $\alpha = 90 - \omega$, $\alpha = 270 - \omega$, values which in effect give the diameters OM, OM′, that is to say the maximum chord.

Opening of the ports and phases of the work. — ρ being the outside lap, i the inside lap, the opening of the port is : for the admission, $e - \rho$; for the exhaust, $e - i$.

If then from the centre O two circumferences be described, one with the radius ρ, the other with the radius i, the portions of the secants comprised between *the circle of the slide* and *the circle of the lap* give the corresponding openings of the ports, either for the admission, or for the exhaust, when these portions of secants are smaller than the port (which, in fact, always takes place for the admission), and when they are greater (which takes place for the exhaust during a portion of the travel), the port is entirely open.

At the origin, for $\alpha = 0$, the port is open : for the admission, by mP_1; for the exhaust, by $m'P_1$; these are the leads.

The admission continues until $\alpha = x0z'$. Then commence the expansion on one side and the compression on the other; they both last while the slide runs over the sum of the laps; the first ceases when the deviation of the slide on the other side of its mean position is equal to the inside lap; the second, when this deviation is equal to the outside lap. If then, we join Os, the expansion finishes when $\alpha = x0s'$; and if we join Ot the compression on the other face finishes when $\alpha = xot'$. From these respective values up to the end of the half stroke, or to $\alpha = 180$, it is the anticipated exhaust which takes place on the motor face, and admission with back pressure on the other (*).

159. *Regulation of the slide with one travel.* — Let us suppose all the elements of the mechanism of the valve-motion stopped : (travel of the slide $2r$; admission lead for the direct stroke, a; laps ρ; extreme widths of the ports λ; total length of the slide d; eccentric rod, b), the length of the

(*) Improved apparatus have been proposed in order to facilitate the study of valve-motions. The *Turin* Engineers School exhibited at *Paris*, in 1867, an instrument of this kind, applicable only to valve-motions with a single circular eccentric, but which, with slight modifications could be adapted to the study of link-motions. This apparatus, founded on the same principle as *Lahire's* gearing, was described in the proceedings of the *Turin* Academy of Sciences, by M. *A. Cavallero* (*).

(*) *Dinamometro, ossia strumento per istudiare le leggi della distribuzione del vapore.* — *Turin*, Imprimerie Royale, 1867.

of the port-face, between the extreme edges thereof : $d - 2\rho$, and its position, follow therefrom.

l being the distance from the small end of the connecting rod to the middle K of the slide, if we take (Pl. V, *fig.* 31),

$$KL = \frac{d}{2}, \quad \text{and} \quad LH = a,$$

$\alpha\beta$ is the position of the outside edge of the left-hand port; the opposite edge m is at a distance from the first : $mH = d - 2\rho$; and the distance mn from the edge n of the slide to the edge m of the port is (*fig.* 52) :

$$pn - pm = a + \rho + \lambda + \rho - \lambda = a + 2\rho.$$

After half a revolution of the axle, the slide has run towards the left by $2r \sin \omega$ (144), and the distance between the two edges n, m, has become : $2r \sin \omega - (a + 2\rho)$.

This is the admission lead for the return stroke; it is thus different from a. The equality of the leads on the two faces is not of great importance in itself; but the symmetry of the positions of the slide, relatively to the ports, when the piston is at the dead points, is on the contrary, an essential condition of a good valve-motion [especially for apparatus with variable expansion, which alone are admissible in locomotives (162).]

Formerly, in order to determine the position of the port-face, the extreme positions of the slide were started from, as seems at first natural.

"It is necessary", said M. *de Pambour* (*), "to make sure that the slide has really an equal play between the three openings of the cylinder, that is to say that, *in its two extreme positions*, it keeps at the same distance from both sides of the mean opening; if this be not so, the length of the slide rod has to be modified."

But for a long time now, builders have been generally following a somewhat different rule, but which is very nearly the same as the preceding when the obliquities are very slight.

What M. *de Pambour* pointed out, had for object to render the two extreme positions of the slide symmetrical with reference to the ports.

That is however of little consequence. What is of importance, is to render symmetrical, with reference to the ports, the positions of the slide which correspond to the *extreme positions of the piston*, at the dead points, or in other terms, to have the same lead for the two strokes.

Hence a small in mass displacement of the port-face, a displacement, the

(*) *Traité des locomotives*, 1840, p. 524.

amplitude of which it is easy to determine. The axis of the central port must be made to coincide, not with the mean of the extreme positions of the middle line of the slide, but with the mean of the positions which it takes between the two extremities of the stroke of the piston.

1st. The distance of the point O from the middle line of the slide, when it is at the middle of its travel $2r$, is evidently :

$$\frac{1}{2}(b + r + b - r) + l = b + l.$$

2nd. The distance of the point O from the central line of the slide, when it is in the centre of the positions corresponding to the two dead points of the piston, is (*fig.* 27) :

$$\frac{1}{2}(OB + OB') = \sqrt{b^2 - r^2 \cos^2\omega} + l$$

or, very nearly :

$$l + b - \frac{1}{2}\frac{r^2}{b}\cos^2\omega,$$

taking only the two first terms of the development. The displacement of the face of the ports is thus $\frac{1}{2}\frac{r^2}{b}\cos^2\omega$. In locomotives, the ratio $\frac{r}{b}$ is not always small enough for this displacement to be neglected, as is admitted in M. *Zeuner's* trace. In one of the examples quoted farther on (175),

$$r = 0.236 \text{ inch}, \quad b = 4.92 \text{ feet}; \quad \omega = 12°10', \quad \text{whence} \quad \frac{1}{2}\cdot\frac{r^2}{b}\cos^2\omega = 0.042 \text{ inch};$$

a very low value, but notably exceeded in other types.

If it were found that this condition is not fulfilled in an engine already constructed, it would be too late to modify the position of the face of the ports, which are in one solid piece with the cylinder. It would be easy to reestablish the equality of the admission leads by giving unequal values to the two laps, the difference between which would be $\frac{1}{2}\frac{r^2}{b}\cos^2\omega$. But it is the equality of the total linear lead which is specially of use, and, in order to obtain it, the transmission itself must be acted on, angles of advance, eccentric rods, rod l. It is at the same time, in any case, the most usual means, the relative position of the driving shaft and the face of the ports being taken as one of the principal given quantities, rather than the length of the rods.

160. The complete expression of the deviation e of the slide referred to the mean of its positions which correspond to the dead points of the piston is, suppressing in that case the term : $-r \sin \omega$ in the expression (2) (155)

$$e = r \sin(\omega + \alpha) + \frac{r^2}{2b}[\cos^2\omega - \cos^2(\omega + \alpha)] = r \sin(\omega + \alpha) + \frac{r^2}{2b} \sin(2\omega + \alpha) \sin\alpha.$$

M. *Zeuner's* trace amounts to neglecting the second term :

" Then " says he (*) " the slide oscillates symmetrically on each side of a point placed at an invariable distance from the axis of rotation O. "

It is clear that the slide with invariable travel performs its complete oscillation, $2r$ in amplitude, on each side of an invariable point : the middle of that travel. Only the values which these deviations relatively to that point take for a given angle α, like those of the deviations relatively to the axis defined just now, depend on the term neglected, that is on the ratio of $\frac{r}{b}$.

It is of consequence however to remark that the values of α which correspond to the dead points of the piston, that is to say $\alpha = 0$, $\alpha = 180°$, render this term *nil;* so that, for these two positions of the piston, the approximate equation or the polar diagram, which is the graphic translation of it, gives exact values of the distances e from the slide to its mean position, values which are : for $\alpha = 0$, $e = r \sin\omega$; for $\alpha = 180°$, $e = -r \sin\omega$.

The dead points of the piston are not, however, the only ones for which the approximate expression gives exactly the corresponding deviation of the slide. The third term becomes *nil*, in effect, also for $\alpha = 180 - 2\omega$.

Beyond these values of α, the diagram does not give exactly the corresponding positions of the slide and of the piston.

§ VI. — Discussion of the valve-motion with rods connected by a link.

161. *Trace of the ellipse of the slide.* 1*st. Stephenson's link.* — The distances run through by the piston are obtained in the manner stated farther back (154). As to the corresponding distances travelled by the slide, the process depends on the mode in which the link is suspended.

(*) *Die Schiebersteuerungen mit besonderer Berücksichtigung der Locomotiven Steuerungen* — 4th edit. 1874, p. 46. *A. Félix, Leipzig.*

The successive positions of the link corresponding to the successive angles described by the crank must be laid down; the distances $\alpha 6$, 6γ, $\gamma 6$,... (Pl. V, *fig.* 53) will give the corresponding travel of the slide.

On the circumference of the two eccentric centres, let us take two semi-circumferences, reckoned the one from the centre o, the other from the centre o', and let us divide each of them into the same number of equal parts 01, 12, 23...; 0'1', 1'2', 2'3'...; and from these points of division, let us describe, with the eccentric rod for radius, arcs on which the extremities a and b of the link will respectively place themselves.

If the latter is suspended by its lower extremity b, the successive positions of this point b will be the intersections of the arcs described from the points 0', 1', 2'.... and of the arc described from the point F with the radius Fb.

The successive positions of the extremity a, will be the intersections of the arcs described from the centres 0, 1, 2.... and of arcs described from b', b'', b'''.... with the chord of the link for radius.

The radius of the link being known, two arcs described with this radius from the extremities so that $a''b''$ give the centre c and consequently the desired position of the link.

The link is suspended also, but more rarely, by its upper extremity. (Example : high speed engine of the Belgian State lines.) The trace is the same.

When the link is suspended by the middle (54), it ought to have in each of its positions, its extremities on the arcs described from the centres 0 and 0', 1 and 1'...., and its middle on the arc described from the point F with the radius FM. In the drawing offices attached to the work-shops, a model is made use, of having the radius and width of the link, and is placed by the eye in such a way that it presents the three conditions laid down.

Determination of the travel of the slide by means of the instantaneous centres of rotation of the link. — For this trace, use may be also made of the instantaneous centre of rotation of the link, a centre which is very easily determined, as M. *Phillips* has shown (*).

It is found (Pl. V, *fig.* 55) on the right line FM normal to the trajectory described by the middle m of the link.

Let O be the position sought. Draw OA and OB, and continue these right lines until they meet in S and T with the radius of the eccentrics continued.

(*) *Théorie de la coulisse*, pamphlet 8vo, and *Annales des mines*, vol. III, 1853.

For a small angle $d.\beta$ through which the link turns, round its instantaneous centre O, the point A describes an arc $OAd.\beta$; now the point of meeting S of the normals to the trajectories of the points A and a is the instantaneous centre of rotation of the eccentric rod, and the distance travelled by the point a is consequently : $OAd.\beta \times \frac{Sa}{SA}$.

In the same way, we have for the distance travelled by the point b, $OBd.\beta \times \frac{Tb}{TB}$; now these distances are equal; then

$$OA \times \frac{Sa}{SA} = OB \times \frac{Tb}{TB}. \quad \ldots\ldots\ldots\ldots \quad (1)$$

Draw OE and OF parallel to Na, Nb. The similarity of the triangles aSA, OAE; bTB, OBF gives :

$$\frac{Sa}{SA} = \frac{OE}{OA}; \quad \text{and} \quad \frac{Tb}{TB} = \frac{OF}{OB}.$$

Substituting in (1), we get OE = OF. The point O is thus on the bisection of the two angles formed by the two rods, so that it is sufficient, in order to obtain it, to continue these bars until they meet in V, to join VN and to continue this line until it meets FM.

This point being known, the extremities of the link in the position corresponding to a small displacement, will be given by the intersections of the arcs described from that point with the radii OA, OB, and of the arcs described from the centres a and b, with the rod for radius. The link is traced in this position, and its centre of rotation is determined which will serve for the construction of a neighbouring position, and so forth, under the condition of proceeding by degrees sufficienty close together that each of the small successive movements of the link may be considered as becoming in fact a rotation round the point determined.

2nd. *Gooch's link* (*fig.* 44). — In order to proceed graphically, it is necessary to construct, as we have just stated, the successive positions of the link, and for each of these, the corresponding position of the rod ot; which is done by placing it in such a manner that it may have its extremities, the one on the link, the other on the right line Ox, and the point of suspension c on the arc of the circle described from the point F with the radius Fc.

3rd. *Allan's link.* — Here again the simultaneous positions of the link and of the rod must be laid down; the latter is placed *by sight*, as has just been pointed out for *Gooch's* valve-motion. The y are the lengths 0.1; 1.2; 2.3 ...

The curves constructed by means of the coordinates thus obtained always

have the general shape already indicated (156); but they evidently go off finer the more the travel of the slide is reduced.

It is clear also that each of the curves given by *Stephenson's* link, has its particular axis, the inclination of which on the x axis increases as the admission diminishes, if the rods are *direct* (Pl. VI, *fig.* 13), and decreases, on the contrary. if the bars are *reversed.*

All the curves have the same axis for *Gooch's* link (Pl. VII, *fig.* 2), and nearly the same axis for *Allan's* link.

162. *Adjustment of the slide with variable travel. Length of the radius of Stephenson's link.* — Let us return now to these valve-motions, and especially to the one most used, that which bears the name of *Stephenson*, and let us see how the rules which practice has arrived at by itself, are confirmed as regards its principal elements, particularly with reference to the length of the radius of the link. Let us seek this length, following the progress indicated by M. *Zeuner* (*).

The paramount condition might be laid down that the slide should occupy always the same position when it is at the middle of the travel, more and more reduced, given to it by the weigh-shaft; in other terms, that the axis, on each side of which it oscillates, should be the same for every travel. But here, as in the valve-motion with invariable travel, it is preferable to consider, instead of the whole travel of the slide corresponding to each of the positions of the lever, the portion of this travel which corresponds to that of the piston; and the question then is so to arrange that the slide, when it is at the middle of the distance thus defined, may have, for *all the values of its travel*, the same position, and may be, on that account, always placed symmetrically with regard to the ports, when the piston is at one of its dead points.

This condition is possible, and easy to fulfil.

In order to express it, it is necessary to find the general expression of the distance from the centre of the slide, occupying the mean between those positions which correspond to a fixed point, to the axis of the driving shaft, for example, and also to lay down that this distance is independent of the position given to the link by the weigh shaft.

Let us define this position (Pl. V, *fig.* 56) by the length u comprised between the middle of the link and the axis. Let $2c$ be the length of the link, very little different from that of its chord. Let us seek the distance of the

(*) *Die Schiebersteuerungen*, 4th edition, 1874, p. 67.

middle B of the slide, to the axis O, when the crank has turned through an angle α from the commencement of the stroke from left to right. We have, l, being the distance MB from the stud to the middle of the slide,

$$OB = OM_1 + M_1M + MB = OF - FM_1 + M_1M + l_1.$$

1 st. *Determination of* OF :

We have $OF = ON + NF = r \sin(\alpha + \omega) + \sqrt{b^2 - (CF - DN)^2}$;

but, $CF = CT - TF = (c - u)\cos\beta, \quad DN = r\cos(\alpha + \omega)$,

then $OF = r\sin(\alpha + \omega) + \sqrt{b^2 - [(c - u)\cos\beta - r\cos(\alpha + \omega)]^2}$.

If (which should always take place), the inclination β of the chord of the link to the perpendicular at Ox is, in all its positions, small enough for its cosine to be taken equal to 1; if further in working the radical out into series, we neglect (which is more or less legitimate, according as the lengths c, u and r are more or less small against b,) the terms which have b^2 in the divisor, we get :

$$OF = r\sin(\alpha + \omega) + b - \frac{c^2}{2b} + \frac{cu}{b} - \frac{u^2}{2b} + \frac{c - u}{b} r\cos(\alpha + \omega) - r^2\cos^2\frac{(\alpha + \omega)}{2b}.$$

2° *Determination of* FM_1 :

We have $FM_1 = CM_1 \sin\beta = (c - u)\sin\beta$,

now, $\sin\beta = \frac{FF_1}{2c} = \frac{OF - OF_1}{2c}$.

OF is known; let us find OF_1.

$$OF_1 = N_1F_1 - ON_1 = \sqrt{b^2 - (C_1F_1 - D_1N_1)^2} - r\sin(\alpha - \omega), \text{ and}$$
$$C_1F_1 = C_1M_1\cos\beta = (c + u)\cos\beta \;\|\; D_1N_1 = r\cos(\alpha - \omega).$$

Carrying forward,

$$OF_1 = r\sin(\omega - \alpha) + \sqrt{b^2 - [(c + u)\cos\beta - r\cos(\alpha - \omega)]^2}.$$

Replacing again $\cos\beta$ by 1, developing the radical and stopping to the 3d term, we have :

$$OF_1 = r\sin(\omega - \alpha) + b - \frac{c^2}{2b} - \frac{cu}{b} - \frac{u^2}{2b} + \frac{(c + u)r\cos(\omega - \alpha)}{b} - \frac{r^2\cos^2(\omega - \alpha)}{2b}.$$

Carrying forward the values of OF and OF_1, into that of $\sin\beta$, we have :

$$\sin\beta = x\cos\omega\sin\alpha - \frac{r}{b}\sin\omega\sin\alpha - \frac{ur}{cb}\cos\omega\cos\alpha + \frac{u}{b} + \frac{r^2}{4cb}[\cos^2(\omega - \alpha) - \cos^2(\omega + \alpha)],$$

value to be carried forward into $FM_1 = (c - u)\sin\beta$.

3° *Determination of* M_1M.— ρ being the radius of the link, we have (Pl. V, *fig.* 57) :

$$c^2 = (2\rho - VH)VH = \text{very nearly } 2\rho VH,$$

$$u^2 = (2\rho - IH)IH = \text{very nearly } 2\rho IH,$$

whence $$VI = VH - IH = \frac{c^2 - u^2}{2\rho};$$

now, $$MM_1 = \frac{VI}{\cos\beta} = \text{very nearly } VI = \frac{c^2 - u^2}{2\rho}.$$

Substituting in OB the values of OF_1FM_1 and MM_1, we have :

$$OB = r\left(\sin\omega + \frac{c^2 - u^2}{cb}\cos\omega\right)\cos\alpha + \frac{ur}{c}\cos\omega\sin\alpha + b + l_1$$
$$+ (c^2 - u^2)\frac{b - \rho}{2b\rho} - \frac{r^2}{4cb}[(c + u)\cos^2(\alpha + \omega) + (c - u)\cos^2(\alpha - \omega)].$$

As the origin of the stroke, $\alpha = 0$, whence

$$OB' = r\left(\sin\omega + \frac{c^2 - u^2}{cb}\cos\omega\right) + b + l_1 + (c^2 - u^2)\frac{b - \rho}{2b\rho} - \frac{r^2}{2b}\cos^2\omega;$$

at the end of the stroke, $\alpha = 180°$, whence

$$OB'' = -r\left(\sin\omega + \frac{c^2 - u^2}{cb}\cos\omega\right) + b + l_1 + \frac{(c^2 - u^2)(b - \rho)}{2b\rho} - \frac{r^2}{2b}\cos^2\omega.$$

Then, during the whole stroke of the piston, the slide travelled definitively :

$$OB' - OB'' = 2r\left(\sin\omega + \frac{c^2 - u^2}{cb}\cos\omega\right) = s.$$

For the maximum travel, and with the double link or its equivalent (150), $u = c$, whence $s = 2r\sin\omega$, we thus arrive at the case of the distribution with independent rods (full admission). If we have further $\omega = 0$, whence $s = 0$; then, for one stroke of the piston, the displacement of the slide is *nil*. Starting from the middle of its travel it returns to it (144).

This admitted, the condition enunciated above amounts to rendering the length constant (*fig.* 56) :

$$Om = \frac{1}{2}(\overline{OB + OB'}) = b + l_1 - \frac{r^2}{2b}\overline{\cos^2\omega} + \frac{c^2 - u^2}{2b\rho}(b - \rho),$$

which ought to be the same for every travel of the slide, that is to say, independent of u, which requires us to have $\rho = b$. *The link ought thus to be described with a radius equal to the eccentric rod.*

This rule is not followed very rigorously : (175, *Lyons* eight-wheeled engines : $b = 4.59$ feet, $\rho = 6.08$ feet) ; at the same time the forward and back-

ward rods are often a little different in length : this is one of the examples of the alterations of symmetry, which allow the conditions of running in gear to be improved.

Om is reduced, for $\rho = b$, to

$$b + l_1 - \frac{r^2}{2b}\cos^2\omega,$$

and OB to : $$r\left(\sin\omega + \frac{c^2 - u^2}{cb}\cos\omega\right)\cos\alpha + \frac{ur}{c}\cos\omega\sin\alpha + b + l_1$$
$$- \frac{4cb}{r^2}\left[(c+u)\cos^2(\alpha_1 + \omega) + (c-u)\cos^2(\alpha - \omega)\right].$$

163. This mode of adjusting the slide, founded on the coincidence of the axis of the central port with the middle of the distance run through by the axis of the slide during a stroke of the piston, was not general some years since, and it is not quite so even now. In the report of the experiments (very interesting ones, to which we shall return) which he made in 1865, M. *Bauschinger* (*), represents the slides of the engines experimented on, placed on the face of the ports at the *middle of their travel.* " The middle line of the slide, only coincides " says he " with that of the central port, if the slide is exactly adjusted. "

It is thus the old mode of adjustment that the author considers as normal.

Beyond the reasons which have led to another method of *fixed* valve-motions (slide with invariable travel) there is, as we see, another for the valve-motions described with a radius equal to the rod; seeing that it is this mode of adjustment, that is to say, the condition : Om constant whatever may be u, which leads to the value, $\rho = b$.

Great amounts of obliquity, the consequence of the length of the eccentric rod being too much reduced and particularly a connecting rod too short, involve, in spite of the equality of the leads at the two dead points, notable inequalities of distribution between the forward stroke and the back stroke, and consequently between the quantities of steam admitted, and the amounts of work acquired by the piston during both.

It will not be without use to point out here that, when this inequality is too marked, it must be taken into account in the direct measure of the work of the steam on the piston. This is what M. *Bauschinger* did in the experiments in question. The indicator, placed nearly in the middle of the cylinder, was provided with a three way cock, which permitted either the

(*) *Indicator-Versuche an Lokomotiven*, pamphlet 4to. — (Extract from the *Civil Ingenieur*. *A. Felix, Leipzig*, 1868.

cylinder to be isolated, or tobe put into communication, by means of sufficiently large tubes, with one or the other of its extremities. Diagrams were thus taken off, as desired, from the two faces.

In the previous, and very instructive experiments, made in 1861, at *Temeswar*, M. *V. Grimburg* (*) took the same precaution, all the more necessary, as the obliquities were very great in the engine on which he operated, especially as regards the connecting rod, the ratio $\frac{B}{R}$ being only 4.5. M. *Grimburg* had applied an indicator to each end of the cylinders, so as to take off simultaneously diagrams from both faces. M. *Bauschinger's* method is sufficient and simpler.

The attentive study of the details of a valve-motion may conduce to a little modification of the ordinary adjustment in order to improve certain points, or fulfil some particular condition. We shall shortly see (175) examples of these small displacements of the face of the ports, relatively to the position which the constancy of the lead on the two faces would assign thereto (162).

164. *Suspension of the link.* — We have supposed u constant for all the values of α, or, in other terms, neglected the vertical oscillations of the link, during the rotation of the axle. The middle I of the link describing an arc of a circle, the point which drives the stud, undergoes by that very fact, vertical displacements the more marked the shorter the suspending rod SI; and the length of this rod is almost always very limited.

A modification imagined by M. *de Landsée*, and applied by M. *Beugniot*, realized at the same time, the connecting rod infinite in length, and the parallelism of the arc, in that case rectilinear, to the axis OX (Pl. V, *fig.* 58).

The suspension rod Sβ, carrying a groove $m'n'$ into which the pin β of the link is let, is continued below for an equal length; the lever SK is continued in the same way by a quantity Ka = KS, and the articulated parallelogram is completed by the sides ab and cb, the latter fixed on an axis of rotation K'. The two sides ab, cS being always quite vertical in all the forms that the parallelogram takes under the action of the lifting lever, the groove $m'n'$ is always horizontal. This simple means of getting rid of the vertical oscillations of the link is not however much in vogue, their amplitude

(*) *Mittheilungen über die mit der Maschine Leopoldstadt angestellten Versuche.* Extract from the *Zeitschrift des Oesterreichischen Ingenieur-Vereins.* — *Vienna*, 1862.

being slight, and consequently the disturbances which they involve, of no importance.

165. *Application of the polar trace to link-motions.* — M. *Zeuner's* polar trace, so simple, as we have seen, for valve-motions with independent rods (158), applies equally to link-motions, provided always that the bars be supposed very long relatively to the eccentric.

Expression of the deviation of the slide. — Making, in OB and O*m* (162) $\rho = b$, and subtracting the second value from the first, we have for the *deviation* e of the slide relatively to the mean of its positions at the two dead points of the piston, reductions being effected,

$$e = r\left(\sin\omega + \frac{c^2-u^2}{cb}\cos\omega\right)\cos\alpha + \frac{ur}{c}\cos\omega\sin\alpha + \frac{r^2}{2b}\left(\cos 2\omega\sin\alpha + \frac{u}{c}\sin 2\omega\cos\alpha\right)\sin\alpha.$$

If r is small enough against b for the third term to be neglected, e is reduced to :

$$e = r\left(\sin\omega + \frac{c^2-u^2}{cb}\cos\omega\right)\cos\alpha + \frac{ur}{c}\cos\omega\sin\alpha.$$

These values apply to direct rods; if the rods are reversed, c is negative, and we have :

$$e = r\left(\sin\omega + \frac{c^2-u^2}{cb}\cos\alpha\right) - \frac{ur}{c}\cos\omega\sin\alpha + \frac{r^2}{2b}\left(\cos 2\omega\sin\alpha - \frac{u}{c}\sin 2\omega\cos\alpha\right)\sin\alpha;$$

and if $\frac{r}{b}$ is small enough,

$$e = r\left(\sin\omega - \frac{c^2-u^2}{cb}\cos\omega\right)\cos\alpha - \frac{ur}{c}\cos\omega\sin\alpha.$$

For the distribution with independent rods, the approximate value was found (158) :

$$e = r\sin(\alpha+\omega) = r\sin\omega\cos\alpha + r\cos\omega\sin\alpha.$$

The deviation of the slide is thus given, by an expression of the same form : $A\cos\alpha + B\sin\alpha$ (A and B being functions of the given quantities ω, r, u, c), and which leads to the same trace.

In his admirable paper of 1853, M. *Phillips* (*) gave for the approximate value of the deviation of the slide, an expression of the same form, but the coefficients were different.

(*) *Théorie de la coulisse*, p. 19, and *Annales des mines*, vol. III, 1853.

Trace of the circles of the slide. — From a point O of a straight line Ox (Pl. V, *fig.* 59 and Pl. VII, *fig.* 1) let us take $OB = \frac{A}{2}$, and at the point B let us raise a perpendicular $BC = \frac{B}{2}$. From the centre C and with the radius CO, let us describe a circumference. The deviation of the slide corresponding to an angle α, described by the crank from the dead point, will be given by the chord OP which makes with Ox the angle α. In effect :

$$\overline{CP}^2 = \overline{CO}^2 \quad \text{or} \quad \frac{A^2}{4} + \frac{B^2}{4} = \overline{CN}^2 + \overline{PN}^2 = \left(OM - \frac{A}{2}\right)^2 + \left(PM - \frac{B}{2}\right)^2,$$

and because of $OM = OP \cos\alpha, \quad PM = OP \sin\alpha,$

$$\frac{A^2}{4} + \frac{B^2}{4} = \left(OP\cos\alpha - \frac{A}{2}\right)^2 + \left(OP\sin\alpha - \frac{B}{2}\right)^2$$

$$= \overline{OP}^2 \cos^2\alpha - A \cdot OP\cos\alpha + \frac{A^2}{4} + \overline{OP}^2 \sin^2\alpha - B \cdot OP\sin\alpha + \frac{B^2}{4},$$

or, reducing,

$$OP = A\cos\alpha + B\sin\alpha.$$

The movement of the slide is thus nearly the same as if it were driven by an eccentric of radius $OK = 2CO$, keyed on at the angle yOK. This is the *fictive* eccentric, equivalent, for each value of u, to the two *real* eccentrics the combined action of which the slide obeys.

For each travel of the slide, that is to say, for each position given by the link to the lifting lever, the corresponding *circle of the slide will* be drawn, the coefficients AB being functions of u; and the discussion will be made, as we have seen (158), for each travel of the slide or each value of u, by the application of the two circles of the laps.

166. *Curve of the centres.* — x and y being the coordinates of the centres of the circles of the slides, corresponding to the variable values of u, we have :

1st. For straight rods

$$x = \frac{r}{2}\left(\sin\omega + \frac{c^2 - u^2}{cb}\right) \quad \Big| \quad y = \frac{ur}{2c}\cos\omega$$

Eliminating u, the geometric locus of these centres is

$$x = \frac{r}{2}\left(\sin\omega + \frac{c}{b}\cos\omega - \frac{4cy^2}{br^2\cos\omega}\right),$$

the equation of a parabola having its axis on the x axis.

For $y = 0$ (value which corresponds to $u = 0$), we have

$$x = \frac{r}{2}\left(\sin\omega + \frac{c}{b}\cos\omega\right).$$

This is the point C_0, the vertex of the parabola, concave on the silde of axis Oy.

2nd. For the rods reversed,

$$x = \frac{r}{2}\left(\sin\omega - \frac{c^2 - u^2}{cb}\right);$$

the parabola, convex towards the axis Oy, has for equation

$$x = \frac{r}{2}\left(\sin\omega - \frac{c}{b}\cos\omega + \frac{4cy^2}{r^2\cos\omega}\right);$$

it has its vertex at the distance

$$\frac{r}{2}\left(\sin\omega - \frac{c}{b}\cos\omega\right) \text{ from the origin } O.$$

167. *Variation of the lead.* — This variation comes out immediately from the expression of the *deviations* e (165). The *linear advance* of the slide is the quantity by which it has exceeded *its symmetrical position with reference to the ports*, when *the piston is at the dead point.* Now with the mode of adjustment indicated (162), it is not in the middle of the travel of the slide that this symmetry takes place, and its *linear advance* is nothing else than the value of the deviation e for $\alpha = 0$. Neglecting the third term we have :

1st. For direct rods :

$$r\left(\sin\omega + \frac{c^2 - u^2}{cb}\cos\omega\right),$$

a value which increases when u diminishes, and reaches, for $u = 0$, that is to say at the dead point of the link, its maximum :

$$r\left(\sin\omega + \frac{c}{b}\cos\omega\right),$$

It is also at the dead point of the link that the maximum opening of the ports is at its lowest value.

2nd. With the rods reversed, the lead $r\left(\sin\omega - \frac{c^2 - u^2}{cb}\cos\omega\right)$ diminishes at the same time as u; for $u = 0$, it is :

$$r\left(\sin\omega - \frac{c}{b}\cos\omega\right);$$

a value *nil* for tang. $\omega = \frac{c}{b}$ and negative for tang. $\omega < \frac{c}{b}$.

Even with direct rods, the admission port is only open at the dead point for an instant, the slide rapidly closing it.

We might have, with both systems of rods, nearly constant leads at the different degrees of expansion in forward gear, giving the forward and backward eccentric sheaves to gear different angles, a means which permits at the same time some other effects to be corrected. But the improvements thus obtained for forward gear, are only made at the expense of backward gear.

168. *Case in which the obliquities are very great.* — The term neglected in the complete expression (165) of the deviation of the slide, can no longer be neglected when the eccentric rods are obliged to be made relatively too short. Thus, the trace no longer gives the simultaneous positions of the piston and slide exactly. Let us remark however, that here again, as for the slide with invariable travel (160), the term in question is *nil* for $\alpha = o$ and $\alpha = 180°$, that is to say at the dead point of the piston. The diagram gives thus exactly the two corresponding positions of the slide, and these are the most essential to know. But it is not the same thing with regard to the values of α close to those which render the neglected term a maximum. In order to take this insufficiency of the trace into account approximately, and in order to avoid deviations in the exhaust especially, which an incomplete study does not render perceptible, M. *Zeuner* advises (*) the addition, on the inside, of the lap of a fraction of an inch. The tendency is less in that way than ever, at the present time. It has been done however, and is still done sometimes. The inside lap, ordinarily *nil*, or nearly so, is often more developed in certain goods engines; those which have short connecting-rods and valve-rods, on account of the short distance from the cylinders to the centre driving axle; it would be misleading therefore to attach this difference in the distribution, to the very fact of the difference of the velocities.

But these attempted modifications are scarcely admissible. If *M. Zeuner's* exceedingly simple trace is generally sufficient for stationary engines, we see that it is not so for many locomotives; and when the approximate methods are not sufficient, recourse must be had to exact graphic processes. Instead of the doubtful correction obtained with the eyes closed, so to say, by a certain increase of lap, especially of inside lap, the trace of the curve must

(*) *Die Schiebersteuerungen*, 4th edit., 1874, p. 39, and 103 note.

always be had recourse to (156) which, taking the obliquities into account, allows their influences to be corrected by trials, laborious enough it is true, but much less so than calculations of the deviations by the complete formula (165), and the trace of the curve in that case which replaces the *circle* of the slide. What besides, is the laying down by points of a few curves, in the whole amount of work which a complete study of the locomotive requires? But it is well even then to apply M. *Zeuner's* trace, as it so easily gives a first approximation, points out the direction of the necessary modifications, and allows the limits of the rigorous discussion to be narrowed.

169. *Length of the link, its inclination.* — This length is arbitrary; it is however limited in both directions, as is easy to perceive.

We have admitted (162) that the inclination β of the chord of a link to a perpendicular to the line of oscillation of the slide, is always very small; it is on this supposition that the expression (162) was obtained :

$$\sin\beta = \frac{r}{c}\cos\omega\sin\alpha - \frac{r}{b}\sin\omega\sin\alpha - \frac{ur}{cb}\cos\omega\cos\alpha + \frac{u}{b} + \frac{r^2}{4cb}\left[\cos^2(\omega-\alpha) - \cos^2(\omega+\alpha)\right].$$

M. *Phillips* gave, with less approximation, the value $\beta = \frac{r}{e}\cos\omega\sin\alpha$, which amounts to neglecting, in the preceding one, all the terms which have b as divisor, and admitting that the angle coincides very nearly with its sine.

The exactness of all that precedes, is thus subordinate to the position that the angle β should never exceed a small number of degrees.

Now, for the given elements, this angle is a maximum when the crank is vertical ($\alpha = 90°$, $\alpha = 270°$), for it is then that the horizontal projection of the chord of the link has its greatest value; and if, in these two positions, and even for full admission, for example, the link MM′ be successively shortened it will be seen that its inclination rapidly increases (Pl. VII, *fig.* 2).

The link ought not then to be too short. To the influence of a too short length on its obliquities, two other considerations are added : on the one hand, the inclination increases the amount of the reactions of the link-pin, which have to be overcome in reversing; on the other, with too short a space between the extreme points which correspond to full admission in forward and backward gears, the link would have an excess of sensibility; to a small movement of the lever there would correspond too marked a change in the running of the slide, and the driver would have a

difficulty in deciding especially with the notched lever and segment, the point for suitable every change in the section of the line.

Conversely, the length of the link has an upper limit; too long, it would not be susceptible enough; a given change in the running of the slide would require a too great displacement of the lever, and on the other hand, the amount of space available for the vertical movements of the link is very restricted in many engines.

170. *Gooch's valve-motion.* — The condition necessary and sufficient, in order that the slide may oscillate symmetrically on each side of an invariable point, is $\rho = \lambda$, λ being the length of the rod which drives the slide. This is at the same time (132) the condition of the constancy of the lead.

Like the preceding one, and even more so this valve-motion includes elements, the exact influence of which is with difficulty apprehended by calculation. Such is, for example, the point of fixing of the link. By operating on *pantins*, M. *Zeuner* (*) ascertained that in order to obtain the most regular movement of the link, this point ought to be, not on the link itself, but outside, next to the concavity and quite close to the chord.

The curve of the centres of the circles of the slide is reduced in this case to a straight line, which is nothing more than the parallel to Oy drawn through the summit of the parabola, the geometric *locus* of the centres in the case of *Stephenson's* link.

171. *Allan's valve-motion with straight link.* — The expression of the distance Om (162), with reference to *Stephenson's* link, is reduced, for ρ infinite, to

$$b + l_1 - \frac{r^2}{2b}\cos\omega - \frac{c^2 - u^2}{2b}.$$

Thus, as u increases, that is to say, as the link deviates from its dead point, the axis m goes farther and farther away from the point O, the leads are more and more unequal for the two strokes of the piston and the valve-motion is thus more and more deranged. The invariability of the point m is perceptibly reestablished by combining as before stated, the two motions of *Stephenson* and *Gooch*.

This fact might have been foreseen. To the first mechanism corresponds a link concave towards the driving shaft; to the second, a convex link and it

(*) *Die Schiebersteuerungen*, 4th edition, 1874, p. 110.

is thus natural that to their combination should correspond a sort of mean, a link neither concave nor convex.

Let us once more seek (Pl. V, *fig.* 60) the general expression of the distance OB from the axis O, to the middle b of the slide.

We have : $$OB = OM_1 + M_1B_1 + l_2 = OF - FM_1 + M_1B_1 + l_2.$$

1st We have found (162)

$$OF = r\sin(\alpha+\omega) + b - \frac{c^2}{2b} - \frac{u^2}{2b} + \frac{cu}{b} + \frac{c-u}{b} r\cos(\alpha+\omega) - \frac{r^2\cos^2(\alpha+\omega)}{2b}.$$

If we represent 1K by u, IM by u_1 and MK by u_2, we must in the expression of OF, replace u by u_1.

Besides, $$FM_1 = KC\sin\beta = (c-u_2)\sin\beta,$$

an expression in which $\sin\beta$ must be replaced by its value (162) :

$$\sin\beta = \frac{r}{c}\cos\omega\sin\alpha - \frac{r}{b}\sin\omega\sin\alpha - \frac{u_1 r}{cb}\cos\omega\cos\alpha + \frac{u_1}{b} + \frac{r^2}{4cb}[\cos^2(\omega-\alpha) - \cos^2(\omega+\alpha)].$$

And $$M_1B_1 = \sqrt{\overline{KB_1}^2 - \overline{KM_1}^2} = \sqrt{l_1^2 - u_2^2},$$

taking approximatively KM_1, KM or $u_2 = \frac{KM_1}{\cos\beta}$.

u_2 being always small against l_1, we can for the radical, substitute

$$l_1 - \frac{1}{2}\frac{u_2^2}{l_1} \quad \text{or} \quad l_1 - \frac{(u-u_1)^2}{2l_1}.$$

Carrying forward into OB, making successively $\alpha = 0$ and $\alpha = 180°$, and taking the half sum, we have for the distance Om from the driving axle to the axis, on each side of which the slide oscillates during the stroke of the piston :

$$Om = b + l_1 + l_2 - \frac{c^2}{2b} - \frac{r^2\cos^2\omega}{2b} - \left(\frac{u_1^2}{2b} - \frac{uu_1}{b} + \frac{(u-u_1)^2}{2l_1}\right).$$

In order that this length may be invariable, the last term, in u and u_1, must be *nil;* whence

$$\frac{u}{u_1} = 1 + \frac{l_1}{b}\left(1 + \sqrt{1 + \frac{b}{l_1}}\right).$$

Now, if we draw TU parallel to the link, we have

$$TU = \frac{l_0}{l_1} u_2.$$

The rods ST and SI (Pl. V, *fig.* 61) are of the same length, when the point K

is at the dead point, that is to say on the axis Ox, I is equally on this axis; and if starting from that position, the lever SS′ turns through a small angle γ, the middle I of the link lowers by MI = very nearly u_1 and T rises by U′T = nearly UT.

Now, $\mathrm{MI} = p\mathrm{S}'$, $\mathrm{TU}' = \mathrm{S}q$, whence $\mathrm{TU} = u_1 \frac{h}{a}$,

and equating the two values of TU, $u_2 = \frac{l_1}{l_0} \frac{h}{a} u_1$; carrying into $u = u_1 + u_2$, $\frac{u}{u_1} = 1 + \frac{l_1}{l_0} \cdot \frac{h}{a}$, and equating the two values of the ratio $\frac{u}{u_1}$, we have for the ratio of the arms h, a, of the lever SLS′:

$$\frac{h}{a} = \frac{l_0}{b}\left(1 + \sqrt{1 + \frac{b}{l_1}}\right).$$

The sign + only being applicable, as the — sign of the radical would give $\frac{h}{a}$ negative.

We find besides for the deviation of the slide, as in the two preceding valve-motions, an expression of the form $\mathrm{A}\cos\alpha + \mathrm{B}\sin\alpha$. The curve of the centres is a parabola, as in the case of *Stephenson's* link.

In general, the leads are not quite constant for all the travels [example (175)], as in *Gooch's* valve-motion, but they vary less than in *Stephenson's*.

§ VI. — On some other valve-motions with a single slide.

172. *Suppression of one eccentric or of the two eccentrics.* — The three valve-motions of *Stephenson*, *Gooch*, and *Allan*, are the most used, but unequally so, the first predominating. These solutions are so simple, and altogether, so satisfactory, that there is perhaps not much interest in seeking for others; many of those that have been tried have been recognized to be inferior to these classical valve-motions. The latter have their faults, without doubt, but these are much less serious than was at first supposed, and are besides amply compensated by the advantage, so precious in locomotives especially, of simplicity of mechanism; as however they are not perfect, there is no harm in endeavouring to improve them further; only the task is a difficult one.

It is chiefly the eccentrics which inventors have attacked. These organs are complained of naturally on account of the work absorbed by their fric-

tion in their hoops, the amount of which is, however, often put too high. Some have wished to suppress one, and others both.

If the idea occurred to take the motion of the slide from the driving shaft, by a transmission similar to that from the piston to the axle, it was recognized at the outset, that this motion could be also taken directly, either from the piston, or from the connecting rod; this seemed indeed more natural and simpler. Mr. *Melling* (*), for example, worked the slide, with invariable travel (Pl. V, *fig.* 62), by a pin *b* fixed on the middle of the connecting rod, taken by a link forming one of the sides of a lever AB, and describing an oval curve having the axis of oscillation of this lever for centre. But this working directly from the connecting rod resulted neither in a simplification of the mechanism, nor in an improvement of the distribution, nor in a reduction in the work of the passive resistances.

It is the same with regard to the arrangement founded on the same principle, and applied later by *Hawthorn* (*fig.* 63) to engines delivered by his firm to the *Versailles* line (left bank). The pin *b* caused a rectilinear link *mn* to oscillate, and the latter the shaft A, carrying two studs *o*, *o'* corresponding, one to the forward gear, the other to the backward gear. The valve-rod *t*, carried two opposite forks, *f*, *f*, *f'*, *f'*, which the lifting mechanism brought on to one or other of the studs.

All that was anything but simple, when it was a question only of imparting motion to a slide with invariable travel.

Working the slide by an oscillating lever, under the combined action of a point on the piston rod, and of a link, is on the contrary, well adapted for the production of variable expansion. This is the distinguishing feature of a certain number of valve-motions, either with a single slide, or with two slides; and which came into favour sometime since.

173. *a. Valve-motions with a single eccentric.* — 1st. *H. von Waldegg's valve-motion* (Pl. VII, *fig.* 4). — The slide receives a combined movement, not in this case from two eccentrics, but from a single one, and from the piston itself.

The eccentric *r*, keyed on at 90° and behind the crank, causes a link CC' to oscillate round the axis J. Into this link runs the extremity of a rod *t*, worked by the lifting lever $\alpha\beta\gamma$, and the displacement of which varies the expansion. The rod *t* acts on the slide, not directly, but by the interme-

(*) *Clarke, Railway machinery*, p. 29.

dium of the lever SM, jointed at S on to an appendage K of the piston head, and at M on the valve-rod, guided at *g*.

The constancy of the lead requires evidently that the link should be circular, and have its centre in the position which the point *p* occupies at the commencement of the travel.

The discussion of this valve-motion proves that it answers suitably to the conditions of the problem. It has the advantage, theoretical, over *Stephenson's* link, of the constancy of the lead; over *Gooch's* and *Allan's*, the advantage of not requiring either such great distances between the centres, or such an amount of obliquity, the rod *t* being placed between the driving axle O and the link, instead of being so beyond the latter. It is adapted particularly to engines in which the slide has to be placed horizontally above the cylinder.

The mechanism is simple enough. Altogether, this valve-motion deserved perhaps to be tried further than it was, but *Walschaert's* is applied in preference.

2nd. *Walschaert's valve-motion* (Pl. VI, *fig.* 7, and II, Pl. LXV). — It is composed of the same elements; indeed it is by *Waldegg's* name that it is ordinarily called in Germany. The valve-rod 0 receives its motion from the lever MS, driven itself, both by the piston rod Q, and by a link CC′ oscillating round the axis J under the action of the single eccentric (replaced in this case by a crank *m*); from this valve-motion to the preceding, we pass by turning the link from left to right, and with it the lever MS and the rod *t*. *Walschaert's* valve-motion requires thus greater distances between the centres than the other, in which the parts return on themselves.

The motion is, at the same time, regular on each side of the piston, and for all the notches, and the lead is constant.

These two valve-motions are far preferable to others of the same family, that is to say with a single eccentric, already quoted (150, Pl. VI, *fig.* 6), and which, patented in the name of M. *Fischer* appears to be due to M. *Walschaert*.

3rd. *Messrs Stewart and Hope's and M. Fink's valve-motions.* — This mechanism attracts, at first sight, by reason of its simplicity; but this quality is exaggerated to such a point as to become a fault, and a serious one. It is ordinarily attributed to M. *P. Fink*, an Austrian engineer. Having in my hands the drawings of an identical arrangement communicated to me twenty years ago, by Messrs *Stewart* and *Hope*, and bearing their name, I abstain from deciding a question of priority to which the

inventors, whoever they may be, themselves attach without doubt but little importance.

Glancing over (*figs* 64, Pl. V and 8 Pl. VI), we see that the inventor must have taken his ideas from *Gooch's* valve-motion. As in that one, the circular link CC′, concave towards the slide, which it works by a rod *t*, movable round the centre I of the arc (and consequently giving constant leads) is supported by a connecting rod which takes it in the middle, and is articulated on the fixed point F. But the two eccentrics of *Gooch's* link merge in this case, into a single one, occupying consequently the mean position between them, that is to say, keyed on to the continuation of the crank; and the single rod, very short, TA, is, no longer articulated, but solidly fixed to the middle of the link, so that the position of the eccentric radius completely determines that of the link. As in *Gooch's* valve-motion, the variation of expansion, and reversing, are obtained by the displacement of the rod *t*, the upper half of the link corresponding to forward gear, and the lower half to backward gear. It is easily seen, in effect, that under these new conditions the link performs not only a backward and forward, but also an oscillatory movement round the point A, a condition *sine qua non* of the variation of the expansion, and of reversing. For the latter, the link must be continued symmetrically below the point A; for engines which do not reverse, to which this valve-motion has been applied, the link, reduced to its upper half, terminates at A.

It does not appear that it has been applied to locomotives, either in Germany, or in Austria; but a lengthened trial on the Great Northern seemed very favourable. In 1859, Mr. *Sturrock* declared that " the economy was so satisfactory, that he would not hesitate to adopt this valve-motion for all engines to be constructed or altered. " Better informed, he afterwards gave up this project. The mechanism in question, is, in fact, not at all suitable to locomotives; it would require, for somewhat considerable admissions, a link of very great length, inadmissible in itself, and also on account of the great obliquities of the rod *t*; and, on the other hand, the suspending or supporting rod AF, ought to be itself of great length, which in practice it would be very difficult, if not impossible.

Fig. 14 (Pl. VI) gives the trace of an egg-shaped curve for 6 degrees of admission of the return stroke. In order to avoid confusion, the curves are represented double. The lower group refers to the motor face, and the upper group to the resisting face of the piston. As in the case of *Gooch's* link, the curves have a common axis, a consequence of the constancy of the leads.

Messrs. *Stewart* and *Hope* proposed a variation (Pl. VI, *fig.* 9) with a straight link, taken by the stud C, attached by a small rod $\alpha 6$ to the piston-rod. But that was only greatly increasing defects already sufficient to condemn the system.

The investigation made in 1860, on a specimen constructed with care (Eastern of France), brought out its disadvantages, and particularly the strains undergone by the parts of the mechanism, which would have required dimensions out of proportion to their useful work.

174. *b. Valve-motions without eccentrics.* — As a matter of course, the motion of the slide may be taken directly from the piston-rod, instead of by the intermedium of the driving shaft. This had been also thought of at the outset of locomotives, but the idea seemed to be given up.

1st. *Stewart.* — It has been taken up recently, and applied to one of the eight-wheeled coupled engines of the *Liège* incline (II, 258 and 259 table). In this case the suppression of the eccentrics had for its principal object the withdrawal of the valve-motion from the effects of the relative displacements which the driving axle and the cylinder undergo under the influence of the suspension springs (154).

Stewart's mechanism (Pl. VI, *fig.* 10) is only, fundamentally, *Walschaert's* (or *Waldegg's*) modified with the view of the result in question, which has been obtained in an ingenious manner, but one difficult to accept. The oscillatory movement of the link of the one side of the engine is taken from the piston of the other side.

The upper half of the link, which corresponds, on the one side to the running in one direction, corresponds, on the other, to running in the contrary direction, each of the pistons being equivalent, relatively to the other, to an eccentric keyed on at 90°, before the crank on the one side, and at 90° behind on the other. The shafts S of the two links are thus prolonged over the whole width of the engine, and the two rods *t*, *t*, ought to take contrary movements under the action of the reversing lever.

Fig. 10, indicates, in elevation, the whole of the mechanism. The full lines refer to the right hand side, and the dotted lines to the left hand side of the engine. The link in full lines C_1 is thus worked by the crosshead K_1 of the left hand piston.

It is difficult to see, as the inventor does, only a slight disadvantage in the absolute dependence of the mechanisms, involving the impossibility of running with a single side in case of the other being damaged. It would be necessary, at least, to know what to take into account, in order to com-

pare the *for* and *against*, to be decided as to the real bearing of the invariability of the working of the slides, when withdrawn from the influence of the suspension. This condition has been realized, and even more completly, in the engines with intermediate driving shaft (II, 251), and nothing warrants us in believing that it produces a notable economy of fuel.

M. Carel's engine (Pl. V, *fig.* 65). The valve-motion of this engine is taken almost exactly from the preceding. The sole peculiarity which it presents is derived from the arrangement of the working mechanism, an arrangement which it is necessary to point out here, for its first appearance (and probably also its last) dates from the Vienna exhibition of 1873. It consists in placing the cylinders horizontal and outside, at a higher level than that of the axis of the driving shaft, and to make up the difference, greater than the stroke of the piston, and the double of the crank, by a lever AB, which performs, in that case, round its axis C, a simple oscillation, and not a complete rotation.

The advantages which are thus obtained are :

1st. The opposition of the movements of the piston, and of the coupling pieces, and consequently more or less complete equilibrium of the disturbing forces (II, 278 and foll.), such as takes place of itself in engines without side cylinders;

2nd. The elimination of the influence of the springs on the valve-motion, the movement of the slides being taken from pieces set up on the frame, as the cylinders : an advantage obtained also by means of the intermediate shaft. The disadvantages are, complication, multiplicity of parts, the exaggerated concentration of the masses suspended towards the hinder end, which leads, in placing the wheels, to a considerable overhanging of the boiler at the front, etc.

An observation already made on other more or less contestable improvements, applies to this. If *Carel's* engine existed alone, what progress would the builder make, who, suppressing the whole concern of transmission, cumbersome and *heavy* (a main consideration), would place the axes of the cylinders, in a plane passing through the axis of the driving shaft!

As to the valve-motion, it is naturally from the oscillating levers that the oscillating movement of the links is taken, that of the left hand being worked by the right hand lever, and *vice versa*.

§ VII. — Numerical examples.

175. Before passing on to the distribution by two slides, let us dwell for an instant on the disadvantages, to remedy which is its object. Some numerical examples are necessary to give an idea of these, an incomplete idea however; for experience does not confirm the importance which is attributed to them.

Let us remark at first that in link-motions, the angles at which the eccentrics are keyed on, vary in fact between very wide limits. These variations would be quite simple if they were in relation to the arrangement of the rods, direct or reversed (151); but they are observed in each of these types, particularly in the first, which is the most usual. They prove, in short, that notwithstanding the restricted number of elements present, they are not yet fixed, and that we have not emerged from the period of guessing. The inequality of the leads in forward and backward gear is equally frequent; it is sometimes introduced afterwards, in order to correct defective valve-motions (167).

The rolling stock of the Eastern of France, only to cite a single group, presents the following examples of the different positions of the eccentrics for the two gears :

SERIES.	ANGLE OF ECCENTRIC.			
	forward.		backward.	
	degrees	minut.	degrees	minut.
136-141 | 158-173 (uncoupled)	18	30	9	30
79-90 | 174-188 (*Crampton*)	20	»	16	»
601-612 (*Crampton*)	27	24	47	24
101-135 | 142-157	22	»	6	»
063-0120	23	»	5	»
189-222 | 243-258	31	»	35	»
261-276 (mixed tank)	38	»	22	»
0121-0164	30	»	35	»
0201-0210 | 0242-0249	12	»	22	»
0501-0525	9	»	36	»
0526-0541	15	»	30	»
0542-0557 | 0558-0569	9	»	36	»

In the case of equal positions, the common value is : 30°.

Lap { outside : from 0.95 to 1.32 inch.
inside : » 0 » 0.24 » } This maximum is found at the same time in *Crampton's* and in low speed engines.

Ports of. ..... » 1.20 » 1.97 »

The eccentric radius r varies from 2.17 to 2.15 inches.

It is clear, at the same time, that this element has no influence on the duration of the events of the work : admission, expansion, exhaust, compression. It only influences the opening of the ports, and the inclination of the link (169).

The Mediterranean slides, shown on Pl. VI (*figs.* 1 to 4), and on Pl. VII (*fig.* 4), are worked by eccentrics keyed on at equal angles, and which are respectively : 9°; 30°; 19°45′; 14°; and 35°.

1st. *Stephenson's link, straight rods.*

Engines 1101 *to* 1130 (6 *wheels coupled*) *of its Méditerranée lines.*

Length of connecting rod.	2.00 feet	Angles of eccentrics front and back...	12°30	Length of eccentric rods.....	4.92 feet.
Stroke of the piston.....	6.09 »			Mean radius of the link.....	4.59 »

FORWARD GEAR.

		TRAVEL OF SLIDE 4.72 inch (maxim.) — Stroke.		TRAVEL OF SLIDE 2.78 inch (minim.) — Stroke.	
		return	back	return	back
Motor face of piston.	Admission..... in hundredths of the stroke	per cent. 77	per cent. 76	per cent. 37	per cent. 30
	Expansion..... in hundredths of the stroke	18	19	41	51
	Anticipated exhaust..... in hundredths of the stroke	5	5	22	19
	Maximum opening of ports to admission.....	inches 2.24	inches 1.26	inches 0.51	inches 0.43
Resisting face of piston.	Free exhaust..... in hundredths of the stroke	90	90	65	57
	Compression..... in hundredths of the stroke	10	10	30	36
	Back-pressure..... in hundredths of the stroke	0	5	5	7
Lead	admission.....	inches 0.20	inches 0.20	inches 0.43	inches 0.32
	exhaust.....	1.02	1.02	1.25	1.18

On the first glance at the diagram (Pl. VI, *fig.* 13), we recognize that it is a question of valve-motion with direct rods, seeing that the leads are greater for the travel of 2.76 inches than for that of 4.72 inches.

Engine le Rhône (*Lyons and Geneva railway*). — *Forward gear.*

NOTCHES OF EXPANSION.			1	2	3	4	5	6	7
Motor face of piston.	Admission	in hundredths of the stroke of the piston.	76.71	71.65	65.19	58.12	47.81	37.45	26.52
	Expansion		15.05	17.28	21.22	24.74	29.56	33.35	25.72
	Anticipated escapement.		8.28	11.07	13.29	17.14	23.63	29.20	57.86
Resisting face of piston.	Free exhaust	in hundredths of the stroke of the piston.	90.71	87.90	84.91	80.72	74.74	68.17	59.60
	Compression		8.57	11.03	13.30	16.69	20.93	25.32	29.73
	Back-pressure		0.72	1.07	1.77	2.59	4.35	6.51	10.67

Engine l'Antée. — *Forward gear.*

Width of the ports		1.77 inch
Lap..	outside	0.94 »
	inside	0.059 »
Angular advance before and behind		28°

TRAVEL OF SLIDE.		4in,72	3in,62	3in,09	2in,76
Motor face.	Admission	p. 100 80,5	p. 100 65,33	p. 100 50,41	p. 100 35,66
	Expansion	14,5	23,33	32,26	38,08
	Exhaust	4,8	11,33	17,33	26,25
Maximum opening of ports		inch 1,42	inch 0,87	inch 0,59	inch 0,43
Resisting face.	Exhaust free	93,7	86,66	80,00	70,25
	Compression	6,1	12,50	18,59	27,08
	Back-pressure	0	0,83	1,41	2,67
Maximum opening of ports		inch 1,77 total	inch 1,77 total	inch 1,46	inch 1,34
Lead	Admission	inch 0,20	inch 0,25	inch 0,27	inch 0,30
	Exhaust	1,08	1,13	1,15	1,19

2nd. *Gooch's link.* — Engines with eight wheels coupled (II, 259), series 2,581-2,512 of the Mediterranean.

The length between centres allowed *Gooch's* link to be applied.

Length of the connecting rod	8.39 feet.
do. of the eccentric rods	4.59 »
do. of the radius of the link	6.08 »
Angles at which the eccentrics are keyed on, before and behind	35°

Width of the ports		1.77 inches
Maximum travel of the slide		5.51 »
Lap.	Outside	1.14 »
	Inside	0.02 »

		FORWARD GEAR.	BACKWARD GEAR.
Constant lead	admission	0.22 inch.	0.18 inch.
	exhaust	1.34 »	1.30 »

The inequality, slight besides (0.039 inch), of the leads on the two faces arises from the axis of the central port being at 0.039 inch from the position of the axis of the slide, the mean of those which correspond to the dead points of the piston; it was preferred in this case to adjust the slide in such a manner that when the admission takes place during 40 per cent of the direct stroke, in forward gear, it is also 40 per cent for the return stroke. The volume admitted is thus greater for the second on account of the space occupied by the rod.

The following table gives for 8 notches of expansion, and for the two directions of running : 1st. in hundredths of the stroke of the piston, the periods of admission, of expansion, and of exhaust, on the *motor* face, for the direct stroke, and for the return stroke; 2nd. the period of compression and back-pressure on the *resisting* face, equally for the two strokes; 3rd. in inches, the maximum opening of the ports to admission.

1. *Forward gear.*

	1st notch.		2nd notch.		3rd notch.		4th notch.		5th notch.		6th notch.		7th notch.		8th notch.	
	Direct.	Back.	Direct.	Back.	Direct.	Back.	Direct.	Back.	Direct.	Back.	Direct.	Back.	Direct.	Back.	Direct.	Back.
	p. 100															
Admission	82,6	78,0	73,0	68,2	62,8	59,0	51,8	50,0	40,0	40,0	30,0	31,2	19,7	21,0	10,0	10,5
Expansion	12,2	14,8	19,0	20,9	25,8	26,3	32,7	31,2	39,8	36,4	44,6	40,7	47,4	44,2	45,9	43,9
Anticipated exhaust (in $\frac{1}{100}$th of the stroke)	5,2	7,2	8,0	10,9	11,4	14,7	15,5	18,8	20,2	23,6	25,4	28,1	32,9	34,8	44,1	45,6
Maximum opening of the ports (inches)	1,59	1,62	1,06	1,12	0,75	0,83	0,56	0,61	0,43	0,46	0,33	0,34	0,27	0,25	0,22	0,18
Period of compression and of counter-steam in $\frac{1}{100}$ th of the stroke	0,30	0,22	0,46	0,35	0,62	0,49	0,79	0,65	0,98	0,85	1,18	1,06	1,44	1,36	1,86	1,86

2. *Backward gear.*

Admission	80,1	77,8	71,9	69,8	61,9	60,0	51,5	50,7	41,4	40,8	31,7	31,4	21,5	20,7	11,8	8,8
Expansion	13,9	14,8	19,2	19,5	25,5	25,1	31,8	30,2	37,7	35,9	42,3	40,4	45,6	44,4	45,2	43,2
Anticipated exhaust	6,0	7,4	8,9	10,7	12,6	14,9	16,7	19,1	20,9	23,3	26,0	28,2	32,9	34,9	43,0	48,0
Maximum opening of the ports (inches)	1,46	1,77	1,00	1,26	0,73	0,87	0,53	0,62	0,39	0,45	0,32	0,33	0,26	0,24	0,22	0,18
Period of compression and of counter-steam in $\frac{1}{100}$ th of the stroke	0,32	0,25	0,45	0,41	0,62	0,53	0,79	0,70	0,38	0,88	1,17	1,08	1,44	1,37	1,89	1,78

We see that for an admission of from 0.30 to 0.32 :

1st. Full expansion, that is to say the expansion of the steam enclosed, only takes place during from 0.40 to 0.44 of the stroke, the exhaust commencing when the piston has still to run from 0.23 to 0.28 of its stroke;

2nd. The ports only open for admission 0.33 inch at the most, that is to say less than $\frac{1}{5}$ th of their width;

3rd. The circumstances differ little from one gear to the other, but more for the two strokes of the same gear.

Another engine equally with *Gooch's* link gave the following figures :

Forward gear.

NOTCHES.	1	2	3	4	5
	per cent.	per cent.	per cent.	per cent.	per cent.
Admission	63	48	32	22	15
Expansion	25	34	43	46	47
Anticipated exhaust	12	18	25	32	38

Here again, to an admission of 0.32 correspond an expansion of 0.43 and an exhaust of 0.25.

There is the following note of the motion adopted by M. *Bousson* (152) :

Ports, 1,35 inch. — Lap { outside ..... 0,98 inch
inside ..... 0 »

Lead { admission ..... 0,16 inch and 0,24 »
exhaust ..... 1,07 » and 1,19 »

Forward gear. — Return stroke.

TRAVEL OF THE SLIDE.			4,72 in	3,93 in	3,34 in	3,03 in	2,75 in
			per cent.	per cent.	per cent.	per cent.	per cent.
Motor face of piston.	Admission	in hundredths of the stroke	80	70	60	50	40
	Expansion		13	20	26	32	37
	Anticipated exhaust	of the piston.	7	10	14	18	23
Resisting face of piston.	Free exhaust	in hundredths of the stroke	93	90	86	82	77
	Compression		7	9,5	13	16,5	21
	Back-pressure	of the piston.	3	0,5	1	1,5	2

At this period, an admission of 40 per cent seemed very limited, and it was judged inexpedient to reduce it further. But we see that, for the same notch, the conditions of the distribution of the work were already, in these old engines, what they are now.

The curves, in rectangular coordinates, of the relative positions of the piston and the slide, for travels of 4.72, 3.34 and 2.75 inches, are represented by *fig.* 5 (Pl. VII). It is at once seen that the axis MM of the central port does not coincide with the middle XX of the slide, in its mean position of the dead points of the piston, seeing that the leads on the two faces (0.24 and 0.16 inch) are different. The axis in question is farther still from coinciding with the middle of the slide at the middle of its travel.

3rd. *Allan's straight link-motion.*

LONDON AND SOUTH-WESTERN ENGINE.

Cylinder : 16 inches diam., 22 inches stroke.

Maximum travel of the slide..... 4,48 inches

Lap { outside..... 0,98 »
inside..... 0 »

Forward gear.

NOTCHES.	1 Stroke.		2 Stroke.		3 Stroke.		4 Stroke.		5 Stroke.	
	direct.	return.	direct.	return.	direct.	return.	direct.	return.	direct.	return.
	p. 100	p. 100	p. 100	p. 100	p. 100	p. 100	p. 100	p. 100	p. 100	p. 100
Admission.....	74	75	63	64	51	51	30	29	11	12
Expansion.....	17	17	23	24	29	32	38	43	38	40
Anticipated exhaust....	9	8	14	12	20	17	32	28	51	48
	inch	inch	inch	inch	inch	inch	inch	inch	inch	inch
Advance to admission.....	0,19	0,19	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25
Maximum opening of the ports for admission.....	1,19	1,00	0,88	0,75	0,63	0,56	0,37	0,37	0,26	0,26

4th. *Walschaert's distribution.*

NORTHERN OF FRANCE CRAMPTON.

Forward gear.

Notches..... / Travel of the slide.....	10 5,24 in — Stroke.		9 4,90 in — Stroke.		8 4,55 in — Stroke.		7 4,19 in — Stroke.		6 3,86 in — Stroke.	
	direct.	return.	direct.	return.	direct.	return.	direct.	return.	direct.	return.
Admission in hundredths.....	78	75	74	71	70	66	65	61	57	56
Advance to admission oin,10 constant.....										
Maximum opening of the ports (inches).....	1,36	1,42	1,20	1,24	1,04	1,04	0,87	0,85	0,67	0,75

Continuation of above table.

Notches.....	5		4		3		2		1	
Travel of the slide.....	3,56 in — Stroke.		3,24 in — Stroke.		3,05 in — Stroke.		2,72 in — Stroke.		2,65 in — Stroke.	
	direct.	return.	direct.	return.	direct.	return.	direct.	return.	direct.	return.
Admission in hundredths.....	48	48	40	39	28	29	9	9	4	4
Maximum opening of the ports (inches).....	0,53	0,57	0,41	0,37	0,30	0,28	0,14	0,12	0,10	0,10

§ VIII. — **Observations on the preceding examples.**

176. *Limit attained by the keying of the fictive eccentric.* — It is useless to multiply these examples. The comparison of the preceding tables is sufficient to bring out the equivalents of the three systems most used. Thus with the third (*Allan's*), for an admission of 0.30, the anticipated exhaust reaches 0.32, and the maximum opening of the port is 0.37 inch. This is very nearly what the two others give on the average for the same admission; and each of the three mechanisms conduces, according to the differences of the particular elements, to differences of the same order as those which are remarked between one system and the other.

It is thus seen that the phases of the application of the work on the piston are not perceptibly effected by the constancy or the variation of the leads, and that the anticipated exhaust, the compression, the throttling of the ports, increase with the expansion nearly equally for the three types; that, in a word, they present in the same degree defects which seemed very serious, and of a nature to limit considerably the application of a large amount of expansion by means which only obtain it at such cost.

Fortunately, the gravity of these defects is more apparent than real; experience has proved it, first by the economy of fuel realized with an admission reduced to 0.30 and even to 0.35, and better still by the well ascertained economical inferiority of some improved valve-motions, exempt from the disadvantages in question.

Those which we have just examined present, beyond, it is true, their limit of application, rather singular circumstances.

In *Gooch's* valve-motion (Mediterranean eight-wheeled engines), for the eighth notch giving a mean admission of 10.2 per cent, the maximum open-

ing of the port is precisely equal to the admission lead : 0.18 and 0.22 inch.

In *Allan's* valve-motion, the maximum opening of admission is only, at 0.26 inch the fifth notch; the admission lead is 0.25 inch; such is, in other terms, the quantity by which the port is open at the moment when the piston commences its stroke. The slide is thus then, in the first case, exactly, and in the second case, to within 0.0039 inch, at the end of its travel. This is then very far from the starting point of the valve-motion, that is to say, of the slide worked by an eccentric keyed on with a slight angular advance (147). In the extreme case in question, the influence of the backward gear rod is so great, that the lead of the fictive eccentric equivalent to the combined action of the two real eccentrics attains 90°!

It is the same thing with regard to the fourth example (*Walschaert*); at the first notch (minimum travel) the maximum opening is 0.098 inch as is the admission lead; the slide is thus, in that case, again at the extremity of its travel when the piston commences its stroke.

For an admission reduced thus to 0.39 or 0.43 inch, the slide with variable travel would give a defective distribution; the work acquired by the piston, not only per stroke (unless by giving to the cylinders excessive dimensions), but also per unit of weight of steam expended, would be very small. The first point is evident; as to the second, experience has proved it; for in the actual state of knowledge which we possess of steam, the geometrical study of a valve-motion is far from being sufficient to ascertain its value. It may be conceived that if the admission cannot be reduced below a certain limit, it is that the anticipated exhaust, the throttling of the ports and the counter admission would then exceed all measure. But as long as things are not thus pushed to extremes, that is to say that the admission does not go down below about 0.20 to 0.25 of the stroke, the *wire-drawing* of the steam, on account of the strangulation of the admission port, does not involve so great a fall of pressure as might be feared. The exhaust lead, apparently so exaggerated, necessarily reduces the mean value of the motor pressure; but it has the advantage, which is the greater, the greater the velocity of the piston itself, of preparing the lowering of the existing pressure in the following stroke; as to the counter-steam, it is only applied hitherto to a very small fraction of the stroke of the piston.

177. *Reaction of the steam from the anticipated exhaust of a cylinder on the steam of the normal exhaust of the other.* — A great amount of expansion presents, for locomotives, and in general for engines with two pistons cou-

pled on to the same shaft, and with one common exhaust, a special advantage, little appreciable with small or moderate admissions, but which it is interesting to point out.

The diagrams taken during long admissions indicate sometimes a rising of the pressure, on the resisting face, much before the origin of the compression of the inclosed steam.

This rising is due to the mutual reaction of the two apparatus.

When, on the one side, the piston approaches the middle of its stroke, the other one is near to the end of the stroke; the anticipated exhaust commences on that side, and the steam, the pressure of which is not weakened by prolonged expansion, is introduced into the conjugate cylinder by the central port, seeing that the communication is free, and compresses therein the rarified steam which the piston was forcing freely into the atmosphere.

With small admissions this reaction is imperceptible, the steam set free on one side by the anticipated exhaust, having only at the end of the long period of expansion a pressure, the excess of which relatively to the steam which flees on the other side before the piston, is much reduced.

It is clear besides that the effect in question may be greatly reduced, even for low degrees of expansion, by rendering less easy and less direct the communication between the two exhausts. In this respect, the two distinct pipes following the contour of the smoke-box to end in the common orifice (II, Pl. XXI, *fig.* 2; XXII, *fig.* 2; XXVII, *fig.* 2; XXXIII, *fig.* 2; XL, *fig.* 5 and foll.) are preferable to the single vertical pipe receiving at its base the steam from the two cylinders (II, Pl. XXXII, *fig.* 2; XLII, *fig.* 2; L and LVII, *fig.* 2). It is sufficient, moreover, in order to adapt the latter to the same conditions as the first, to place in it a diaphragm isolating the two cylinders, as M. *Meyer* did long ago.

Altogether, there is little ground for preoccupation with respect to an influence which is only manifested in the case of very lengthened admissions, and very rarely attained in practice.

The examination of the diagrams taken off by means of the indicator has reduced to its just value, even for degrees of expansion, already considerable the bearing of the defects of the valve-motions with a single slide. It is true that the indications of these diagrams, very explicit and very exact for slow speeds of the piston, are less so for high speeds. The inertia of the movable parts of the instrument intervene then, and the trace ceases to be simply the expression of a series of successive states of equilibrium between the external forces applied to the piston of the instrument.

It is, independently of the not less important question of maintenance, the comparison of theamounts of fuel consumed, which ought, definitively, to pronounce bet ween the various types. And if, for engines with a high piston speed, like locomotives, the objections to valve-motions with a single slide are without weight, it is easy to see that the motions with two slides, theoretically more perfect, but also more complicated, may, in the end, procure no appreciable economy of fuel. This is effectively what takes place. Thus they are almost entirely given up now. On a line in Germany justly famed for the progressive spirit which presides over the construction of the rolling-stock, and all the details of working, that from *Cologne* to *Minden*, all the expansion slides have been suppressed, without the consumption of fuel being effected.

While yielding to the evidence, to the experience which has led in almost all cases to the same conclusion, some courage was necessary to give up a problem attractive in itself, and which seemed to have a positive tendency of a progressive nature. Thus, however well founded it may appear, this discouragement was only temporary. Some engineers see in the actual rise of the pressures admitted, an argument in favour of expansion with two slides. Without doubt it is in the application of a greater degree of expansion that the advantage of a more elevated pressure principally exists, and with two slides, the expansion may be pushed much farther than with one. But for locomotives, there is, independently of all consideration of details of mechanism, a limit which does not exist on stationary engines; it is only when it has, by exception, but little work to do, and not under the normal conditions of its service, that a locomotive can run with very low admissions; at the present time, the work of the expansion exceeds habitually that of full admission; the link allows this to be carried farther, and the steam to be well utilized, probably up to the minimum of admission compatible with the special conditions of locomotives.

However that may be, the brief examination of expansion, by means of two slides, has a marked place in this book. We cannot refrain from citing a remarkable example (180) of the awakening of the spirit of research in this order of ideas.

§ IX. — Variable expnasion by means of a special slide.

178. In valve-motions with two slides, the elements of the distributing slide are determined by the consideration of the leads for the complete

stroke (146 and foll.); there is only a slight outside lap, giving a small amount of expansion, and an inside lap *nil*, or even negative. For smaller admissions, the steam is cut off by a special valve, which ought evidently to satisfy this main condition : that the admission, once intercepted, may not recommence until the end of a stroke. It is of consequence also that the introduction should vary between very wide limits, that it may be nearly the same for the two strokes, direct and return, and that the apparatus may act for backward gear as for forward gear.

For certain engines, this last condition might be dispensed with; but not so as regards those which, running short distances, go and return without having been turned, as is the practice (especially in England) to a considerable extent.

Gonzenbach's expansion. — This expansion, one of the most defective there is (it in no way fulfils the main condition of variable admission within wide limits), was applied during a certain time. The expansion slide runs on a diaphragm dividing the valve-box into two compartments, and pierced in the same way with two openings; the admission takes place, or is suspended, according as the openings correspond or not. This arrangement, borrowed from old stationary engines, presents one disadvantage which is of itself sufficient to cause it to be rejected : that the clearance space is thus increased by the whole of the excess of the volume of the lower compartment over that of the slide itself. Anterior, if not to the discovery, at least to the general application of the link under the different forms, it was thus combined at first with motions with independent and forked eccentric rods, then with the link.

In the first case the expansion slide was worked by the eccentric rod which was not in gear, that is to say by the back one for forward gear.

Figs 6 and 7 (Pl. VII) show the arrangements made with this effect. In the first (*fig.* 6, *Veloce* engine), the distributing slide was vertical; the transmission, direct for that slide, was indirect for the expansion one in forward gear. For backward gear, at the same time that the fork F′ took the place of F on the pin *b* of the slide rod of distribution, the supplementary fork *f* was applied on to the pin *b′* of the lever, the pin of which *b″* was let go by the supplementary fork *f′*.

In the second (*fig.* 7, *Hercule* engine of the Alsace line), the lever *ab*, transmitting the motion to the expansion slide, was always worked by the hind eccentric, a simpler arrangement which suppressed the additional forks, but which rendered the expanding apparatus quite unsuitable for backward gear.

This defect is to be found, moreover, in the applications subsequently made to engines with a link (Pl. VII, *fig.* 8).

In the latter, the distributing slide is worked by a *Stephenson's* link, CC', which ought only, in principle, to serve for reversing, but which, in reality, may be also used for reducing the defects of the expansion apparatus.

The block receives the motion of the circular link DD', oscillating round D, under the action of the connecting rod *b*, articulated at a point K on to the hind eccentric rod. The travel of the block, and consequently the expansion, vary with the point at which the link takes the rod *t*.

This link, arranged for running forward, worked always by the same rod, cannot serve for running backward, as it would them give rise to reintroduction of steam. The expansion block should be reversible as is the distributing slide : a complication which could only be avoided by paralyzing the expansion slide during backward running, that is to say by putting the rod *t*, at the bottom of the link on the side of its axis of rotation D. Advantage could then be taken of *Stephenson's* link in order to utilize, by the reduction of the travel of the slide, the expansion it might give.

But it is far better still to keep to the latter, and suppress an apparatus which offers no advantage, not even in theory; and which, during rather a long period was attended with a partial success out of all proportion to its real value.

179. *Expansion by means of a slide sliding on the distributing slide.* — In order to do away with the first disadvantage of the preceding motion it is sufficient to apply the expansion stud directly on to the back of the distributing slide; their relative movement thus determines the commencement of the expansion.

The functions of the second remain exactly the same as in the preceding case. Only, its form should be modified so that it may receive the expansion slide. The admission ought to be made by two ports arranged in the one, and which the other, sometimes reduced to a simple block, sometimes to a central orifice, shuts at the desired moment.

The variation of the expansion may be obtained, either by the variation of the travel of the stud, as in *Gonzenbach's* expansion, as is also the case with respect to *Polonceau's* expansion, or by the variation of the width of the stud, as in *Meyer's* expansion.

180. *Polonceau's expansion* (Pl. VI, *fig.* 11). — *Polonceau's* valve-motion

presents, at the same time, a simplicity of mechanism and an elasticity of functions which at first greatly predispose in its favour. Theoretically, it seems almost irreproachable.

The distributing slide T is worked by a *Gooch's* link. So is the expansion piece *d*, *d*; which has necessarily its link, but neither special eccentrics nor rods. The same rods *b*, *b*, are jointed on to two links, solidly connected together, C, C′, which in elevation project the one over the other. The two lifting rods *t*, *t*′ both ending at the common centre O, receive from two lifting levers *l*, *l*′, two independent motions.

Suppose at first that the distributing slide is always at the bottom of its travel, and serves only for reversing. The minimum admission corresponds then to the maximum travel of the expansion piece, that is to say, to the position of its rod *t*′, at the dead point. The first slides under the second nearly fixed, and brings its ports under it, while those of its face are still open.

If the rod *t*′ of the expansion stud is placed, like the rod *t*′, at the extremity of its link, the two movable parts travel on solidly together without relative movements, and the position is the same as if the special expansion apparatus did not exist. In general, as soon as the two rods cover each other in elevation, whatever may be the common position, we simply return to *Gooch's* valve-motion with a single slide.

Nothing prevents advantage being taken of the variability of the travel of the distributing slide; the constancy of the leads, of the commencement of the compression, and of the anticipated exhaust, is then more or less influenced.

The following is, for forward gear, an example of the division of the stroke of the piston between the three periods of motor work for different degrees of expansion, the distributing slide being always at its maximum of travel :

Notches.....	4		6		8		9		10		11	
	Stroke.		Stroke.		Stroke.		Stroke.		Stroke.		Stroke.	
	direct.	return.	direct.	return.	direct.	return.	direct.	return.	direct.	return.	direct.	return.
	P. 100	P. 100	P. 100	P. 100	P. 100	P. 100	P. 100	P. 100	P. 100	P. 100	P. 100	P. 100
Motor face { Admission.....	40	33	30	26	20	20	15	15	16	11	5	6
Motor face { Expansion.....	52	59	62	66	72	72	77	77	82	81	87	86
Motor face { Anticipated exhaust.....	8	8	8	8	8	8	8	8	8	8	8	8
	inch	inch	inch	inch	inch	inch	inch	inch	inch	inch	inch	inch
Maximum opening of the ports for admission.....	0,79	0,71	0,75	0,67	0,71	0,67	0,67	0,63	0,63	0,59	0,55	0,59

The commencement of the exhaust depending only on the position of the distributing slide, and the latter having, by hypothesis, the same position for all the degrees of expansion, it is natural that the exhaust should always commence at the same point of the stroke of the piston.

As to the maximum opening of the port of admission, it decreases much less in this case than in the distribution by a single slide, but it is not constant.

During admission, in effect, the steam ought to pass through the two ports : that of the slide, more or less covered by the expansion piece, then that of the face, more or less covered by the slide; the effective opening is the smaller of the two.

This expansion suits backward as well as forward gear, a property which it possessed exclusively, among expansions with two slides, before the appearance of M. *Guinotte's* (180).

These conditions seem assuredly satisfactory, save the inequality of the distribution on the two faces, an inequality which only affects appreciably very small and very large admissions, and disappears completely for those of 20 per cent. It is clear, besides, that far from meeting with the indifference andill-will with which experiments are greeted which the authorities dare not formally refuse, the application made on the *Orleans* lines, at the time when M. *Polonceau* was at the head of the locomotive department, was received at first amongst the staff (excepting perhaps by some drivers) with good will and a sincere desire to develop its advantages.

However, its lengthened application proved that this valve-motion, so logical in design, produces no economy, and that it has no superiority over the valve-

motions with a single slide. The North Eastern of Switzerland has arrived, according to M. *Zeuner*, at a different conclusion, but if that really be so, it seems difficult to put in the balance the experience of the Swiss line, with that of the French line. When an arrangement has been given up, notwithstanding powerful personal motives in its favour, we may readily believe that this has been done only on the best grounds.

The additional resistances, that is to say the friction of the expansion piece and the corresponding increase of friction of the eccentric hoops, would thus be sufficient to compensate for the advantages attending a more logical method of distribution. Perhaps also the best possible result has not always been obtained from its various elements. Thus, in the preceding example, an anticipated exhaust of 8 per cent. of the stroke is probably insufficient for great piston speeds; and the lead, excessive in appearance, which, with a single slide, is the consequence of great amounts of expansion, is not perhaps so exorbitant as it seems. If however, a great anticipation of the exhaust is necessary for high piston speeds, that which is sufficient for a certain admission, is sufficient *a fortiori*, at the same speed, for a less admission, and the increase which attends it in valve-motions with a single slide, can then only be detrimental. Constant as it is in *Polonceau's* expansion, it may be suitable at the same time for large and small admissions, the latter corresponding generally to greater speeds.

In *Börsig's* expansion, the distributing slide, similar to *Polonceau's*, is worked by a *Stephenson's* link, with reversed rods. The expansion piece, with large central orifice, cuts off the steam, not by its outside edges as in the preceding case, but by its inside edges. It is worked by the back eccentric, which renders the apparatus altogether unsuitable for the use of the expansion for running backwards.

181. *Valve-motion of Couillet's engine*, exhibited at *Vienna* in 1873, *Guinotte's* system (Pl. VI, *fig.* 12). — The two slides superposed have the same form as those of *Polonceau's* valve-motion.

The distributing slide is always at full travel; the lever which commands it is only fixed in three positions : full admission forwards, backwards, and the dead point. It is moved by a *Walschaert's* mechanism, that is to say, by a beam PS, oscillating under the double action of the piston, and of the rod *t*, which itself receives motion from the link C, C′, oscillating round the point T under the action of the single eccentric, keyed at 90° on to the driving crank.

The expansion slide receives motion from a link KK′ by means of the rod N,

which ordinary lifting pieces allow to be brought into connection with any one of the points of the link.

The latter receives its complex motion, on the one part from the beam PS, which acts on it through the bar m, articulated on to the extremity n of the lever; on the other, from a second beam UV oscillating round the point H, under the action of the piston rod, and which takes and supports the link at the point U, placed below its middle.

The following figures were taken, at the *Louvain* work-shops, from a wooden model, full size.

FORWARD GEAR.

Constant travel of the slide : 4.57 inches.

Notches	1		2		3		4		5		6		7		8	
	STROKE.		STROKE.		STROKE.		STROKE.		STROKE.		STROKE.		STROKE.		STROKE.	
	direct.	back.	direct.	back.	direct.	back.	direct.	back.	direct.	back.	direct.	back.	direct.	back.	direct.	back.
Motor face of the piston.																
Admission in $\frac{1}{100}$ th of the stroke	P. 100 78	P. 100 78	P. 100 67	P. 100 67	P. 100 58	P. 100 57	Q. 100 48	P. 100 47	P. 100 41	P. 100 40	P. 100 36	P. 100 30	P. 100 20	P. 100 20	P. 100 10	P. 100 11
Expansion do	18	18	29	29	38	39	48	49	55	56	66	66	76	76	86	85
Exhaust do	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Maximum opening of the port to admission	inch 1,53	inch 1,61	inch 1,53	inch 1,61	inch 1,53	inch 1,61	inch 1,53	inch 1,61	inch 1,53	inch 1,61	inch 1,53	inch 1,61	inch 1,53	inch 1,61	inch 1,53	inch 1,61
Advance to admission	inch 0,20	inch 0,20	inch 0,20	inch 0,20	inch 0,20	inch 0,20	inch 0,20	inch 0,20	inch 0,20	inch 0.20	inch 0,20	inch 0,20	inch 0,20	inch 0,75	inch 0,20	inch 0,20
Travel of the expansion slide	inches 7,48	inches 7,48	inches 6,06	inches 6,06	inches 5,39	inches 5,39	inches 5,08	inches 4,84	in hes 4,41	inches 4,41	inches 3,86	inches 3,86	inches 3,31	inches 3,31	inches 2,87	inches 2,87

Resisting face of the piston	Free exhaust	96 p. 100	for all degrees of expansion.
	Compression	4 —	do.
	Counter steam	0 —	do.

This valve-motion presents great regularity on the two faces, which is due to its happy cinematic combination, and also to the great length of the driving rod 8.07 feet.

The admission may vary between 0.10 and 0.78, *in either forward or backward gear.*

The anticipated exhaust appears to be too tardy, in the preceding example.

Negative inside lap. — The engine in question offers an example of a negative inside lap (148) or of a space in the distributing slide (*fig.* 12). According to the choice of the given quantities, this resulted from an equation which leads, according to the cases, to a positive value, or to a negative value. It can be at once conceived in principle, that a negative inside lap ought to be the consequence of the smallness of the linear advance (the sum of the admission lead and of the outside lap) which may be insufficient for the exhaust). In this case the inside space is 0.077 inch for an outside lap of 0.71 inch, and ports 1.34 inches. The admission lead being 0.20 inch, the linear advance is 0.91 inch, and the interior space of 0.079 inch carries the exhaust lead to 0.98 inch. *Meyer's* distributing slide often presents the same peculiarity.

Other engines of the same type, but with the ordinary valve-motion, being attached to the same work, the comparison of the consumptions of fuel will give the measure of the practical value of M. *Guinotte's* expansion.

It is remarkable in itself, and the more so because it is deduced, as a particular case, from a general theory of valve-motions with two slides.

This theory, due to M. *Guinotte*, has been developed in a very lucid manner, and completed in a series of articles full of interest, by M. *S. Pichault* (*).

M. *Zeuner* has explained and applied it in a more rigorous manner in the 4th edition of his classical work on slide valve-motions, an edition in which the whole of the part relative to expansions with two slides has been entirely revised, and treated with a generality which, while giving this part of the work a more scientific character, will render it at the same time still more useful, and applicable in practice.

182. *Meyer's expansion.* (Pl. VII, *fig.* 9.) — The distributing slide, of the same form as *Polonceau's*, is worked by a *Stephenson's* link, which only serves for reversing. (The variation of its travel can, however, be utilized;

(*) *Annales industrielles*, 6th year, 1874.

M. *Bauschinger* quotes one of the locomotives of the Bavarian railway, the driver of which had succeeded in thus effecting considerable economies). The expansion slide, moved at first by the piston-rod, but with the interposition of a lever of the first order, then, as is far preferable, by a special eccentric, is solid, as in *Polonceau's* valve-motion. The sole essential difference is that the expansion varies in the latter by the variation of the travel of the click, and in the other by the variation of its length. In order to reduce the admission, the one must be diminished and the other increased. This variability, this elasticity of the click is realized by forming it of two parts, joined together by a right and left hand screw, which allows their distance, and consequently the total width to be changed.

The steam being cut off by the coincidence of the outside edges of the piece with the port of the distributing slide, this coincidence ought to take place so much the later the more the admission has to be prolonged ; it is to the maximum admission that the minimum width $\beta\beta'$ of the expansion piece corresponds ; its two halves are then in contact; to the minimum admission on the contrary the maximum width of the piece corresponds, that is to say the maximum distance between its outside edges β, β'; $\beta b, \beta' b'$, measures then the expansion which the primitive piece ought to undergo on each side, in order to pass from the first limit to the second.

It is always necessary that the admission, once intercepted, should not recommence until the end of the stroke. This condition, as may be conceived, will oblige the extreme limits of expansion to be narrowed. It is possible, in effect, that the length of each half of the piece, fixed by the condition of maximum admission, may be too much reduced to prevent a re-introduction when their distance apart corresponds to a great degree of expansion. The outside edges cut the steam off at the desired moment, but if the half pieces are too short, the steam may come in behind their inside edges.

In order to pass from one admission to the other, the two edges, β, β' ought to run through distances which are not quite equal for the same introduction on the two faces. If it were only two expansions that had to be reconciled, this effect of the obliquity of the rods would be easily remedied by giving different pitches to the right and left hand screws. But the ratio which would be suitable for two expansions would not do for a third.

This circumstance is neglected. The two pitches are the same, which only involves, by the way, inequalities without great consequence in the distribution on the two faces. In order to produce the expansion or contraction of the piece the driver turns a handle m (*fig.* 9). This move-

ment is transmitted by the gearing i to the square continuation k of the screwed shaft. The latter is joined to the rod articulated on to the eccentric rod l by a joint which yields to this movement of rotation.

M. *Meyer's* expansion presents some analogy with M. *Farcot's*, which itself is derived from that of Mr. *Edwards;* in 1840 the latter had been applied to a locomotive, but without success, as was easy to foresee.

We know that in M. *Farcot's* more perfect mechanism, each of the expansion pieces taken along by the distributing slide is stopped in its travel: in one direction, by an eccentric cam, and more or less early, according to the point which it presents; in the other direction, by the side of the steam chest against which butts a rod fixed to the piece, as soon as it has come back to the position which corresponds to the commencement of the stroke of the piston. Admissible for slow running engines, these shocks of the pieces would very soon dislocate the mechanism in locomotives.

But the modification imagined by M. *Meyer* had not only for effect the elimination of a mode of action which became impossible. With *Farcot's* expansion, the admission is necessarily less than half the stroke, because the port must be closed by the piece before the slide has reached the extremity of its travel, and consequently before the piston is at the middle of its stroke. The locomotive could not adopt so limited an admission.

Meyer's mechanism gives great latitude in this respect, especially in forward gear. For backward gear, the conditions are less satisfactory; but in this the question is only of a slight defect, and not of an impossibility, as for *Gonzenbach's* expansion (178).

Theoretically, *Meyer's* expansion is satisfactory, but not more so than *Polonceau's*; as mechanism it is more complicated, and it has the drawback, (which at the same time could be avoided by means often proposed) (*) of not yielding to as prompt a variation of the admission, or better speaking, to the instantaneous suppression of the expansion. Experience having condemned the second, one can scarcely comprehend how the first could be tolerated before it.

(*) The most simple is due to M. *Rydel*, and MM. *Sulzer* apply it with success to stationary engines. It consists in giving convergent directions to the ports of the distributing slide, as well as to the edges of the expansion piece, formed of a portion of a cylinder which slides on the outside face, equally cylindrical, of the principal slide. The variation of admission is obtained by a simple rotation round its axis, of the expansion piece formed in this case all in one. Nothnig would prevent the application of this ingenious modification to locomotives.

Meyer's expansion, had, in effect, the same fate as *Polonceau's*. Greeted with considerable favour, especially on the State railways in Bavaria, it received very numerous applications during a number of years. And this long test was the cause of its being given up, as the fact was well established that its troublesome maintenance was not compensated by any appreciable economy of fuel.

The expansion slide with central orifice is in some respects, for certain mechanisms, better suited for variable expansion than the solid slide, such as *Polonceau's* and *Meyer's*. But this peculiarity has not in itself any great influence. Thus, M. *Zeuner* cites *Bréval's* valve-motion (Pl. VII, *fig.* 11), in which the expansion piece, with central opening *o*, conducts the steam into a small channel *c*, *c*, made in the distributing slide : a form much adopted, as we shall see later on, but for a different reason.

In discussing this distribution, M. *Zeuner* has proved that it presents the same defects as *Gonzenbach's*. We must admit however that it has an advantage over the latter : it does not increase the clearance space.

183. Whatever may be the future reserved for the principle of valve-motions with two slides, it occupies in the present day too unimportant a place in railway rolling stock to warrant longer developments on our part. We shall not then stop for their analytical and graphical discussion. The reader who wishes to enter more deeply into the subject should refer to the 4th edition of M. *Zeuner's* work.

Let us only recall the principle established as far back as 1857 by the learned author (*), a very useful principle for the discussion of valve-motions founded on the use of an expansion valve applied directly on to the distributing slide. It may be enunciated thus : Let (Pl. VII, *fig.* 13) 1st, *a* the centre, and $Oa = r$ the radius of the fictive eccentric of the distributing slide, that is to say (165) of the circular eccentric which would impart to that slide the absolute movement which it takes for a given position of the link, under the action of the two *real* eccentrics; 2nd, *b* the centre of the eccentric of the expansion slide of radius $Ob = r_0$. Joining *ab* and drawing OA parallel and equal to *ab*, Oc is, in magnitude and direction, the radius of the circular eccentric which would give the expansion slide, moving on a fixed plate, a movement absolutely identical to its relative movement on the distribution slide.

(*) 4th edition, page 200.

The question is thus brought down to following the motion of the expansion slide led by this *resultant* radius, relatively to the edges of the ports of the distribution slide supposed fixed; and its *deviations*, for a given rotation α of the axle, are given again by an expression of the form

$$A \cos \alpha + B \sin \alpha,$$

in which

$$A = r \sin \omega - r_0 \sin \omega_0$$
$$B = r_0 \cos \omega_0 - r \cos \omega,$$

that is to say by the secants of the corresponding circle.

Resuming, the sole fact of requiring an additional complicated mechanism, aggravating the maintenance, multiplying the risks of damage, and consequently, of breakdowns, is, in the matter of locomotives, a grave objection, which could only give way to economical advantages fully ascertained.

The advantage, on the other hand, is not slight of being able to control, by a single organ, the expansion, and the reversing. To work with counter-steam in the presence of an obstacle, of a signal to stop, the driver has only one lever, or better, only one screw to work. With a special expansion slide, he has of course to work that also, in order to obtain, by complete admission, all that is possible from the counter-steam. Two levers to work instead of one, more numerous parts, more difficult maintenance, explain and justify the little predilection of the drivers for these perfected valve-motions.

With the link-motion and single slide, the locomotive possesses a simplicity of mechanism which we would not hesitate to purchase, if were necessary, by a certain excess of consumption of coal; but this main advantage of simplicity requires no sacrifice; while hitherto, under whatever form it has been applied, the special expansion slide has produced no appreciable economy. In spite of the excessive velocity in appearance of the piston, the locomotive with simple valve-motion can however bear, for the consumption per horse-power, comparison with the best stationary engines without condensation. Moreover, the observation made in commencing (3), on the subject of the motor apparatus properly called of locomotives applies equally to the classical mechanism of their distribution. It could not receive a more striking sanction that in its very frequent application to stationary engines to which it was optional to adapt other arrangements.

CHAPTER V.

DETAILS OF THE CONSTRUCTION OF SOME PARTS OF THE MACHINERY.

184. The various arrangements of the vehicle in locomotives, and the construction of the boiler, required developments without which it would have been impossible to see clearly up to what point the whole has been successfully adopted to the very varied conditions of plan and of speed; the stability of the engine, and the resistance of the boiler to the pressures, continually increasing which it has to bear, have however too great an influence on safety, to be treated summarily.

The economy of fuel, either in the reduction of weight consumed, or by the use of coal of indifferent quality, is, on the other hand, of such interest as would have justified greater details on this point, if the limited extent to which this book must be restricted did not oblige us to measure the space for each of the subjects dealt with, not only according to its absolute importance, but also according to its amount of speciality.

This character of speciality is much less marked in the driving machinery, and valve-motion of locomotives, than in the vehicle and the boiler. Arrived at this point, the study of a locomotive scarcely brings in other considerations than those which are common to all stationary engines, high pressure, reversing, and without condensation. The complete description of the parts of the machinery, the discussion of their form, and their dimensions, would not thus be in their place here, and would lead us besides much too far. Bearing in mind the branches of knowledge which taken together form the common foundation of the different arts involved in the constructing of engines, we shall present only on the principal organs of the machinery of locomotives some observations which appear not to be omissible. They might for the most part, have found their place in the preceding chapters, but it seemed preferable not to interfere with the exposition of the main subject, by details of construction.

§ I. — Cylinders.

185. *Their volume.* — The primary given quantities for the determination of the elements of a locomotive, are: the load which it has to draw over a line of given section, and the uniform speed at which it has to draw that load. Hence results the effort of traction measured on the pistons, and from that effort is derived, — given the pressure in the boiler, the stroke of the piston during admission, and the diameter of the driving wheels — the function d^2l (II, 149 and foll.), d being the diameter, and l the stroke of the piston.

But these two dimensions ought also to be regarded from another point of view.

From the velocity is derived the heating surface, the latter having to produce in the unit of time a weight of steam, the volume of which, brought to the pressure in the cylinders during admission, is equal to the volume produced in the same time by the two pistons.

S sq. ft. being the heating surface,

K lbs. the mean weight of steam per second and per square foot of heating surface,

δ the specific weight of the steam at the pressure which it possesses in the cylinders during admission,

$\frac{l}{q}$ the fraction of the stroke of the pistons during which the steam is admitted,

D the diameter of the driving wheels,

n the number of turns of the wheel per second, and consequently $V = n\pi D$ the speed,

The volume of steam U to be expended per second is $\frac{SK}{\delta}$. (1)

The volume engendered by the two pistons during admission is, per turn of the wheel: $\frac{\pi d^2 l}{q}$, and per unit of time $\frac{n\pi d^2 l}{q}$ (2); equating (1) and (2), $\frac{d^2 l}{S} = \frac{Kq}{\delta n \pi}$.

If the evaporation per mean square foot, the pressure of the steam, and the normal number of turns of the wheels were the same for the different types of engines, the function $\frac{d^2 l}{S}$ would be constant for all the types. The following table indicates the constancy to which this is carried out in practice:

ENGINES	S	ABSOLUTE pressure in the boiler.	DIAMETER of the wheels. (D')	d	2	$d^2 2$	$\frac{d^2 2}{S} = \frac{Kq}{\delta n \pi}$	$\frac{d^2 2}{D}$
			I. MEDITERRANEAN.					
	sq. feet.	atm.	feet.	feet.	feet.			
Free wheels. Crampton (6 wheels). . . .	1038,21	9	6,89	1,31	1,97	3,3805	0,003	0,495
Passenger Eng. (Bourbonnais).	1265,88	»	5,38	1,47	id.	4,2949	0,003	0,796
Id. Id.	1299,03	»	id.	id.	id.	id.	0,003	0,796
H. S. (4 coupled wheels).	1345,53	8,5	6,56	1,44	2,13	4,4393	0,003	0,678
Goods Eng. 6 coupled W. (1401-1488). .	1392,04	8	4,26	1,47	id.	4,4847	0,003	1,087
Id. Id. (1794-1813). .	1392,04	9	id.	id.	id.	id.	0,003	1,087
Id. Id. (1813-1903). .	1248,66	9	id.	id.	id.	id.	0,003	1,087
Id. Id. (Bourbonnais).	1420,57	»	id.	id.	id.	id.	0,003	1,087
Id. Id. Id.	775,03	»	id.	1,15	1,97	2,5957	0,003	0,602
8 coupled wheels.	2147,26	9	4,13	1,77	2,16	6,8337	0,003	1,646
			II. NORTHERN.					
H. S. (4 coupled wheels).	986,22	9	6,89	1,41	2,00	4.0190	0.004	0,581
8 coupled wheels.	1759,96	9	4,26	1,64	2,13	5,7389	0,003	1,345
			III. ORLÉANS.					
H. S. (4 coupled wheels)	1473,74	9	6,63	1,41	2.13	4,2450	0,00288	0,645
8 coupled wheels.	2250,17	9	4,22	1,64	2,13	5,7389	0,00252	1,356
10 coupled wheels	2260,50	9	3,51	1,64	1,97	5,2975	0,00233	1,507
			IV. SOUTHERN					
6 coupled wheels.	1567,26	9	4,26	1,47	2,13	4,6476	0,00295	1,087
			5,25	1,47	2,13	4,6476	0,00295	0,882
			V. EASTERN.					
8 coupled wheels.	2175,68	9	4,13	1,64	2,16	5,8272	0,00262	1,410
			VI. SUBURBAN. (Ceinture) (Kœchlin).					
8 coupled wheels.	1347,47	8,5	3,94	1,51	1,97	4,4858	0,003	1,141
			VII. BELGIUM.					
8 coupled wheels.	1475,25	9	3,44	1,57	1,80	4,4746	0,003	1,291
			VIII. ITALY.					
6 coupled wheels.	1344,14	9	4,33	1,47	2,13	4,6476	0,003	1,076
8 wheels (la Rampe)	1862,22	7	3,94	1,77	1,84	5,7672	0,003	1,463
8 wheels (l'Apennin)	2046,08	8	3,94	1,97	2,00	7,7555	0,00377	1,969
			IX. ENGLAND.					
North London (4 coupled wheels). . . .	1023,58	10	5,08	1,41	2,00	3,9837	0,00384	0,785
— (american type Patrick). .	1198,50	»	7,08	1,50	2,33	5,3857	0,00449	0,753
			X. GERMANY AND AUSTRIA.					
Wurtemberg (H. S.) 4 coupled wheels. .	1077,18	»	6,00	1,42	2,00	4,0896	0.00377	0,678
Semring (Sigl. Eng. with 8 coup. wh.).	1829,93	9	3,63	1,64	1,97	5,4740	0,00295	1,507
Hungarian-Galitzian Railway (8 wh. Sigl.)	1927,34	8,5	»	1,70	2,00	5,7283	0,00295	»
			XI. UUNITED STATES.					
Fairlie Pacific) 4 cylinders.	1872,98	»	12 wheels of 3,48 12 wheels of	1,25	2,00	6,2227	0,003	1,786
Engines with 12 wheels of Millholland.	1399,36	»	3,00	1,67	2,20	6,0638	0,0043	2,045
Engines with 10 wheels of Madison incline.	1380,20	»	3,67	1,69	2,00	5,6930	0,0042	1,550

We see that, with the exception of the *Orleans* and Eastern of France, engines, in which it is notably inferior, the ratio $\frac{d^2l}{S}$ is nearly constant, and oscillates about 0.0033. But this approximate constancy in no way implies that of the elements of the function $\frac{d^2l}{S}$ or of its equal $\frac{Kq}{\delta n\pi}$; that would be scarcely possible, so long as n varies. For the same motor apparatus, the value of this function should be greater for low speed engines, seeing that the normal velocity of rotation, or n, is, in their case, generally smaller than in the others.

While sufficing for a large amount of expansion in passenger engines, cylinders are often too small in goods engines; and if the function $\frac{\delta n\pi}{Kq}$ keeps appreciably constant, it is that the diminution of n is nearly compensated by a correlative reduction of K. As we have seen, (II, 386) the production is diminished, deliberately or rather by habit, which is equivalent to reducing the heating surface S, seeing that it is less utilized; or indeed, when this production has to be forced, as on steep gradients, the smallness of the cylinders leads to excessive admissions (II, 415). In one case as in the other, economy is sacrificed.

With expansion variable by one slide, which allows the admission to be usefully reduced to a greater extent than was supposed, there is no fear of making the cylinders too large. In low speed engines, large dimensions should be boldly given to them; and, in certain types, the difficulty is, in reality, to make them large enough.

Large cylinders allow of expansion, particularly at the normal speed, while causing the boiler to produce all the steam possible, and, consequently, what it ought to produce; they greatly facilitate starting, when the rails are in good order; it is particularly with this object that the Metropolitan engines, for example, with continual stoppages, have very voluminous cylinders.

The ratio $\frac{d^2l}{S}$ should never go below 0.0033, and it should exceed that figure in low speed engines, especially if the wheels are not very small, and if the fire-box is large, that is to say, if the grate = at least $\frac{1}{70}$ of the surface S. The too frequent insufficiency of the cylinders of this class of engines, is, however, diminished to a certain extent, by the progressive elevation of the pressures.

The example cited (II, 415) characterizes well the situation in which goods engines are too frequently placed, especially those which work on steep gra-

dients, where they are obliged to lower their velocity nearly to the limit compatible with adhesion, or from 7.5 to 9 miles an hour; the engines only then run with such an extravagant admission as 0.93, because the cylinders are too small to use with expansion, the steam which the boiler is capable of producing.

186. *Proportions of the cylinders.* — d^2l being determined, $\frac{l}{d}$ is ordinarily taken $= 2$, in stationary engines and when this value is deviated from, it is rather below. The length and the weight of the frame is thus reduced. In locomotives, where all the elements are in such strict mutual dependence, the ratio adopted results from the special conditions for each type. Short distances between centres require, under the penalty of exaggerating the obliquities of the connecting rods and the valve-rods, short strokes, and consequently, large diameters of piston. In the same way, in high speed engines with driving wheels of moderate diameter, a reduced stroke is necessary in order to avoid excessive speeds of the parts, that is to say, large diameters again. Low speed engines have small wheels, especially if they are intended for running on sharp curves; the small wheels allowing the distance between the centres to be reduced, and facilitating, with the same distance between centres, the passage of the flanges within the rails; the stroke is, then limited by the necessity of keeping the big ends of the connecting rods, at a sufficient height above the line, but the diameter of the piston is, on its side, farther limited by want of space, especially in engines with inside frames and cylinders.

Altogether, the ratio of the two elements of the cylinder is often obligatory; thus, the consideration of the curves to be passed through having led M. *Beugniot* (*) to stop at 3.94 feet for the diameter of the wheels of his *mountain* engines, this figure limited the length of the crank to 11.02 inches, or $l = 22.04$ inches; the diameter d resulted in that case from the condition of having, with a pressure of 7 atmospheres in the boiler, and an admission of 0.75, an effort on the piston equal to the adhesion at $\frac{1}{7}$, or $\frac{48.00}{7} = 6.86$ tons; which gave $d = 21.26$ inches, and $\frac{l}{d} = 1.04$, an unfavourable proportion, assuredly; but at times, proportions, more unfavourable still, have to be admitted (II, 257, 262).

The stroke being decided, as well as the thickness of the piston (which

(*) *Bulletin de Mulhouse*, vol. XXX, p. 488.

often reaches 5.51 inches), and the clearance spaces, the finished length of the cylinder follows. On the Eastern of France, for example, these spaces are fixed thus (*general order* No. 5 rolling, stock, art. 78) :

" The dimension lengthwise of the cylinders ought to be such that, when the piston is fixed to the connecting rod, the clearance at the end of the stroke should be 0.59 inch at the front, when the tightening up has the effect of lengthening the piston rod, and 0.39 inch at the back; and, on the contrary, 0.39 at the back and 0.39 at the front, when the tightening up shortens that same rod (196). "

187. *Thickness of the cylinders.* — It is useless to dwell on the thickness of the cylinders; it is taken large enough (1 inch at least), in order to meet the wear and especially the fresh boring out required by changes of form; and this boring out often has the effect of reducing somewhat the insufficiency of the initial volume.

The diameter is a little increased at the two ends, throughout the extent of the clearance, in order that future boring out should not interfere with the fitting of the ends.

It is of consequence that the cast-iron should be hard enough to bring the wear more especially on the rubbing parts of the piston. On the Belgian State railways three per cent of tin is added to the cast-iron for the cylinders, which appears to produce a considerable increase in the resistance to wear.

As to the ends, it is desirable that their resistance should be less than that of the connection, so that in case of accident, such as a key coming out, a connecting rod breaking, or the introduction of some extraneous substance, the end may give way, and leave the cylinder intact.

The hermetical closing of the covers is often insured by the interposition of a copper wire of the section indicated (36 and Pl. I, *fig.* 17), which crushes under the tightening of the bolts.

188. *Blow-off cocks. Cylinder valves.* — The carrying over of water by the steam, the condensation which is effected by the expansion, independently of all subtraction of heat by the colder sides, or by that action, tend to accumulate water in the cylinders. It is let out by means of *blow-off cocks*, inserted to the number of two at the bottom of each of the cylinders, and which the driver works by means of a rod.

The negligence of drivers being likely to involve accidents, such as knocking out the end of a cylinder, the hand cocks have been sometimes (*Krauss'* engine), replaced by automatic blow-offs, valves opening within from outside, kept open by a small spiral spring and closed by the steam.

The use of these apparatus has not spread, and they have even been given up by those who adopted them, notwiths tanding the small advantage which they offer of doing away with the noise produced by the ordinary blow-off cocks. It is only at starting, and after a lengthened stoppage, or when the level of the water is very high, that the driver requires to blow-off, and he is warned of the necessity of this operation by the shower of water which escapes from the chimney. In fact, experience proves that the danger which it was desired to prevent is far from being serious. M. *Gottschalk* has however informed me of this fact: engines with eight wheels coupled of the first deliveries made to the Southern of Austria, have had their piston rods put out of straight on account of the accumulation of water in the cylinders, the rods, of *Bessemer* steel being 3.15 inches in diameter. These accidents determined them to carry, by turning down the cover, the height of the clearance on the front end of the cylinder from 0.20 to 0.28 inch (a very low figure), Further, in the latest engines, the steam space has been increased by carrying the diameter of the cylindrical barrel from 4.69 to 4.92 feet. An end is thus put to accidents which the careful use of blow-off cocks ought certainly to have prevented.

The cylinders of marine engines are provided with ordinary safety valves, opening from inside outwards, loaded by means of springs, and allowing the water to pass when their load is exceeded by the internal pressure; this does not exclude blow-off cocks, either automatic, or worked by hand. But many engineers reject the former because of the prompt obstruction of the orifices by the fatty matters arising from the lubrication of the cylinders. The valves are sometimes provided with levers, which allow them to be worked by hand; they become in that case regular hand blow-off cocks.

Locomotive cylinders have sometimes also had safety valves applied to them (*Orleans* ten wheeled engine : valves of 0.78 inch, pressed by a spiral spring), but it was a question in that case of obviating an accidental excess of pressure in the boiler during the use of counter-steam (217); thus the valve was not put into communication with the cylinder except during the use of the counter-steam. This communication was established by the working of the blow-off cock, arranged accordingly, that is to say, with two ways.

§ II. — Pistons.

189. *Advantages of a small mass.* — If it is desirable, in general, to neglect no means of lightening the locomotive, the lightness is more neces-

sary still for the parts with relative movements, because of the parasite movements which they tend to impart to the whole mass, and of the efforts which they develop (II, 278 and foll.).

There would be however, from another point of view, a certain utility in not reducing too greatly the mass of the piston, and of the parts attached to it. This arises from the considerable amount of expansion now in use which it is even desirable often to push beyond the point where the useful effect obtained from the unit of weight of the steam ceases to increase, on account of the imperfect distribution of the steam then manifested (176). By thus reducing the admission, when the engine has only a slight amount of work to produce, the expenditure of steam is reduced, while keeping up the normal pressure in the boiler.

The movement of rotation being uniform, the velocity of the piston is accelerated during the first half of its stroke, and retarded during the second. Now, for large amounts of expansion, the mean effective pressure of the steam on the piston is also much greater during the first half than during the second, and so is the work applied to the piston. This inequality is diminished by the action of the masses, the work which they have stored up during the acceleration being restored during the retarded movement. A portion of the excess of work expended by the steam, during the first half of the stroke, is thus brought on to the second half, and reduces the disproportion of the mean efforts directly applied to the piston, the mass of which acts thus as a sort of regulator.

It is thus that in stationary engines, running with very small admissions, like *Allan's* engine the mass has been systematically increased, and especially the speed of the piston, and of the connected organs, a condition without which the compensation indicated would have no importance.

But if considerations of this nature can be usefully applied in the case of stationary engines, it is quite otherwise for a system so *free* as the locomotive is, in which the necessity is, above everything, to reduce as much as possible the forces of inertia. The consideration of stability, of the disturbing actions exerted by the parts with relative movements, is thus paramount, while that of the inequality of the distribution of the work of the steam during a stroke of the piston, is very secondary; besides, with the two engines coupled together at 90° on the axle, the movement is accelerated for one of the pistons, when it is retarded for the other.

190. *Their nature and their form.* — In France, pistons are almost exclusively of wrought-iron. Cast-iron is a good deal used in England (*Great*

Northern) for engines of small power, and particularly in Austria (*Northern of Austria*), etc. The wrought-iron piston is ordinarily a simple plate (Pl. VIII, *figs* 1, 4, 5, 10), made by stamping out a disc brought to a bright red heat. The double or hollow piston, very much used also (II, Pls XXXI; XXXIV, *fig.* 1; XXXVI, etc.), is formed of two similar plates, but less thick, welded together at their edges. One of the plates is then pierced with a small hole to prevent air being confined inside.

With the single plate, it is desirable, in order not to increase the clearance space, that the front end of the cylinder, which faces the hollow of the piston, if the latter is flat on the other side, and, in the contrary case, that the two cylinder-covers should be made according to the shape of the piston, (Pl. VIII, *fig.* 12 *c*, *c*). It is in order to avoid this complicated and weak form of the end, that the double piston, which, besides, is more massive, is often preferred.

The single piston with a flat bottom has been sometimes changed into a hollow piston by the addition of a second plate, *p*, *p* (*figs* 7 and 9). The last figure represents a *compound* piston, the ring of which is formed of a circular angle iron attached by rivets. Nothing would warrant this complication, considering the ease with which stamping out is done; the question is thus of an old piston with cross pieces and springs, altered into a Swedish piston (192).

In cast-iron pistons, in the single piece, the holes for the support and the removal of the core are sometimes closed by five or six screws, *b*, *b* (*fig.* 8), which serve at the same time to consolidate the plates. On the Northern of Austria, where they attach importance to the reduction in the weight of these pistons (which, by the way, work exceedingly well there), the holes, only three in number, are closed by simple screw plugs.

191. *Attachment of the rod.* — *Figs* 1 to 5, and 7, 9, 10 (Pl. VIII) indicate the different modes in use. Putting the block hot on to a slightly conical bearing of the rod, with the latter riveted over cold, if it is in wrought-iron (*fig.* 5), appears preferable to a screwed bearing, either conical (*fig.* 10) or cylindrical (II, Pl. XLVII; XLV, etc.), and, to the nut screwed on to the screwed continuation of the rod (*figs* 3, 4, 9), which requires a corresponding hollow in the cylinder cover. Sometimes, in order to avoid riveting over cold, the bearing portion of the rod is equally heated, but by this the tightening due to the contraction of the block when it is heated alone is lost. It is true that in that case the countersink may be deeper.

When the rod is in cast-steel, it is desirable to bring the body of it to a red

heat. The moderate heat transmitted to the bearing of the rod facilitates the driving up, without damaging the metal. The key (Pl. VIII, *fig.* 1, K), very much adopted formerly in the piston with cross bars, between which it was placed, is now little used.

Well done, putting on hot never gives way. Thus the piston, forged in a single piece with its rod, as in Belgium, has no other advantage than a little more lightness, on account of the partial suppression of the central enlargements.

192. *Piston segments.* — The body of the piston is turned to a diameter a little less than that of the cylinder. For a diameter of 17.32 inches of the second, for example (Pl. VIII, *fig.* 1), the first is turned down to 17.24. The difference (too slight doubtless in this particular case) is made up by metallic segments, *s*, *s*, *s*, either in steel, in antifriction metal, or in cast-iron, which should be in contact with the surface of the cylinder, but should exert on it as slight a pressure as possible.

It is often laid down in principle that the segments ought to be in cast-iron less hard than that of the cylinders, in order that the wear should come chiefly on the first. Some builders however prefer hard cast-iron, which, with good lubrication, takes, a fine polish and wears the cylinders but little.

In the old pistons, the segments were pressed by means of springs, provided with inside screws which were obliged to be regulated from time to time, after taking off the cylinder-cover and the front plate of the piston. These complicated organs have given place everywhere to the almost identical types, *Ramsbottom's* and the Swedish. The block receives, in grooves, segments which, put in by force, tended to open by their elasticity.

In *Ramsbottom's* piston (*figs* 3 and 4), the segment *s'* is continuous and helicoidal; in the Swedish piston (*figs* 5, 7, and 10) it is circular and split. We shall occupy ourselves only with the second form, the long helicoidal segments, which often used to break, being generally given up.

There are almost always two segments, put in side by side into the same groove, or more ordinarily, each in a special groove, and of course with broken joints.

The pressure on the inside of the cylinder diminishes with the wear; but experience proves that the circles may lose half their thickness and still remain tight, at the same time without producing, when they are new, an exaggerated pressure and consequently increased friction.

The rings, cast separately, or cut out of long cylinders, are often eccentric

on the inside, are turned down to a diameter greater than that of the cylinder, and split at their points of minimum thickness. Sometimes their external periphery is not quite circular, in order that they may take exactly that form when the joint is made and they are screwed up.

The joint is broken, which permits, strictly speaking, leakage to be prevented with a single ring, as in the Belgian piston; the thickness and consequently the weight of which are notably reduced.

In the above example (*fig.* 1) the segments are turned to the diameter of 17.68 inches, that is to say 0.35 inch more than the cylinder. In order to compensate this difference, a piece must be taken off of $0.35 \times 3.1416 = 1.11$ inch; instead of taking it off over the whole thickness of the segment, which would give a straight joint, two grooves are made (hatched portions of *fig.* 2 *b*) which give, in the segment in place (*fig.* 2 *a*) the broken joint $\alpha\beta\gamma\delta$. The tightening results from the tendency of the segment to return, from its actual diameter of 17.32 inches, to its primitive diameter of 17.68 inches.

Putting on. — Opening the joint, the ring is run on to the large diameter of the piston, then, in slipping it along, it is got into its groove. In order to put the piston in its place, the projection of the circles is driven in by a sheet iron collar. This collar does not penetrate into the cylinder. It is sufficient that it seizes on to a portion of the width of the ring, and as soon as the latter is let into the cylinder a little, the collar is removed.

The thickness of the rings is limited : on the outside, by the condition of supporting without too much strain, the *opening* required to place them on the piston; within, by the condition of performing a lengthened term of work, that is to say of losing a notable thickness by wear before their elastic force becomes too much reduced. In steel, they are ordinarily 0.59 inch in maximum thickness. With cast-iron, deformation might alter the elasticity, or even determine fracture; thus the thickness is often less. But the cast-iron in that case is only the rubbing surface; the elasticity is supplied by an inside ring in steel, called *false segment.*

Pressure of the segments. — The piston, separated from the connecting rod, ought to be easily moved by hand. Otherwise, the tightening is excessive.

The tightening ought, at the same time to be a little greater in steam than when cold, the piston heating and expanding more than the cylinder, which is imperfectly protected against cooling, when it is outside (II, 232).

Jackets of cork or of woollen rags maintained by a wooden or sheet-iron sheathing, have however an efficacy which is at once manifest, according to several engineers, by a considerable economy of combustible.

Excepting this influence of temperatures, more or less different, the friction of the piston and its rod is independent of the pressure of the steam. It is the only piece of the machinery which is so.

By submitting the question to calculation, M. *Résal* found (*) for one of the types of engine of the Mediterranean system with steel segment, a pressure of 18,5 lbs on the inch, and for another type with cast-iron segment, and false segment 17,1 lbs on the inch.

This figure is subject perhaps to rather considerable deviations. But it is chiefly the coefficient of friction which undergoes great variations, according to the lubrication, nature and state of the surfaces.

193. *Packings pressed by the steam.* — The independance of the pressure of the segments and pressure of the steam has been criticized, and not without plausible reason. What is the advantage of that pressure when the hermetical closing is not necessary, that is to say when the engine runs with the regulator shut? It is then even the more injurious, as the suspension of the lubricating action of the steam soon brings on griping.

Hence the idea of applying the segments to the surface of the cylinder, not in a permanent manner by their elasticity, but only when that is necessary. It is the steam which in that case fulfils the function ; it is admitted, through a small opening o, o', 0,12 inch in diameter, in the annular space comprised between the ring and the bottom of the groove (Pl. VIII, *fig*, 10).

An objection arises at first sight against this contrivance, viz. that while requiring two segments it only utilies one in the direct stroke, and the other in the return stroke.

It has however been applied for a long time on the great Southern and Western Railway, where it is said to prolong notably the durability of the segments and that of the cylinders, while giving (as should be the case) very tight pistons. If this were really so, it is not easy to understand how a detail of construction giving such good results without notable complications, should be thus neglected.

194. *Piston with double rod.* — It is often found, in horizontal engines, that the cylinder becomes oval, in consequence of the more rapid wear of the lower part under the action of the weight of the piston. If, in principle, it should be so in engines with heavy pistons and with long stroke, this fact is less explainable in locomotives in which the piston is light, and

(*) *Annales des mines*, vol. V, p. 38, 1874.

the rod relatively very rigid, taken and guided even to the end of the stroke towards the front, for a considerable length. It is not easy to understand particularly why the maximum of wear of the cylinder should be, as is often stated, towards the middle. If this maximum were due to the weight of the piston, and the bending of the rod, it should correspond to the maximum amount of overhanging, that is to say, to the front end of the cylinder.

Be that as it may, the complete suspension of the piston by the continuation of it srod is considered by some engineers to have the effect of reducing the wear of the cylinder, and they accept the stuffing-box which that suspension requires (Pl. VIII, *fig.* 12, and II, Pl. LIII). It is however a question of diameter. On the *Orleans* lines, suspension is applied, starting from 1,48 feet, a figure to which a considerable stroke always corresponds, ordinarily 2,13 feet (II, Pl. LVIII).

With pistons too heavy and segments rendered too flexible by wear, the lower edges of the wrought-iron plates might act upon the surface of the cylinder which gives bad friction. Sometimes this effect is provided for by a slight eccentricity in the plates. But the double rod, more complicated without doubt, is more sure. The front-rod is often, in the interest of the men, covered in by a sheath, but this does not prevent the continuation of the rod from rendering the consequences of a slight collision more severe by affecting the whole machinery. A deputy locomotive superintendent on the *Lyons* railway, M. *Tourdot*, also proposed the continuation of the rod, but with another object. Each of the extremities worked a connecting-rod. The effort of the steam on the piston was thus divided between two pairs of uncoupled wheels, as if they were coupled. But coupling is preferable to this expedient, as it also is to the use of four cylinders (II, 257).

Sharp and Robert have made hollow piston-rods, a form for which there is little ground because it leads to the increase on the one part of the external diameter of the rod, and on the other of the inequality of the admission on the two faces.

195. *Lubrication of the cylinders and of the slides.* — The steam, being moist, lubricates the rubbing-surfaces. It is then particularly when the engine is running with the regulator shut, as on long inclines where the use of counter-steam is not required (203), that the lubrication, properly so called, is necessary. Long ago this was endeavoured to be supplemented by a very slight admission of steam, sometimes direct, sometimes inverse, sometimes intermittent, sometimes continuous, which (148, 3rd) gives always a certain resistance to the movement. The object is attained in a more

complete manner by a slight injection of steam into the exhaust. But all have agreed however, on this point, that actual greasing is indispensable in order to have fine rubbing-surfaces, and slow wear.

The old processes, which are still frequently used, only allowed the greasing to be done during the stoppages, or while running with the regulator closed.

During the last years, divers processes of automatic lubrication have been proposed and applied. They are not yet perfectly practical, so that ordinarily apparatus worked by hand are still employed, but which the driver can work from his place.

One of the best is the reservoir with three cocks (Pl. VIII, *fig.* 13) which allows the lubrication to be done by an easy operation, and whether the steam be admitted or not into the cylinders. The oil is introduced at B by the cup A, the cock 1 being open and 2 and 3 closed; in order to lubricate without steam, it is sufficient to open 3; to lubricate with steam, 1 is closed and 2 and 3 open; the pressure from the boiler then drives the oil into the cylinder.

Although the slides profit a little by the lubrication of the cylinders, they ought also to be lubricated directly. The preceding apparatus, of which the tube of emission branches into two, distributes the oil at the same time to both. If the lubrication of the slides fails, the face of the ports loses its polish, scratches, and ought to be planed down if their thickness permits, or if not, replaced. An efficient lubrication is the more indispensable the higher the pressure, the pressure of the slides on the port-face not being, like that of the segments of the piston, independent of the tension of the steam. The difficulty of preventing the griping of the slides is for many engineers, the principal objection against the increase of the pressure. The saline deposits, carried over by very wet steam, often come in at the same time to aggravate the conditions of the friction. That does not however prevent high pressures from prevailing more and more; thus the last technical meeting of German engineers at *Düsseldorf* advised ten effective atmospheres to be attained, but in that case good lubrication is perfectly indispensable.

M. *Krauss* applies an automatic lubricator to the slides, but which only acts as such when the regulator is closed. The oil reservoir surmounts a small vertical pump screwed on to the cover of the steam chest, and containing a piston; lifted by the steam when it comes into the box, this piston intercepts the communication with the reservoir of oil; lowered by the pressure of air when the regulator is closed it reestablishes that communication.

There are in engines, without counting axle-journals, many other rubbing-surfaces which require more or less perfect lubrication, according to the load per unit of surface and the amplitude of the slidings : connecting-rod ends and coupling-rod ends; axle-box slides, and cross-head slides; links, eccentric clips, stuffing-boxes of the piston-rods and slide-rods; the compensating-beam spindles; reversing lever or screw, regulator, and regulator-lever, sand-box, blow-off cocks, gauge-cocks, break-rods; valve-levers, etc. But whatever may be the importance of the lubrication, we cannot, from the motive indicated (184), dwell here on arrangements in considerable variety, notwithstanding their simplicity applied to those organs which work outside.

Neither can we stop to examine the lubricating materials employed in locomotives. Tallow and vegetable oils are the principal ingredients. Mineral oils, too fluid besides, are more detrimental than useful when the rubbing-surfaces are heated. An observation which does not of course apply to the slight addition of petroleum, which is often necessary in England to prevent freezing.

§ III. — Connecting-rods

196. *Driving-rods.* The driving-rods are alternately drawn, and compressed. When they are short, their tendency to bend may be neglected, and it may be admitted, in the second case as in the first, that the strain is distributed uniformly through the cross section; but it is not so in many existing locomotives, in which the length of the driving-rods reaches, and sometimes even exceeds 8,53 feet. (II, Pl. XLIII, *bb*.)

The symmetrical form relatively to the axis, combined with an enlargement of the centre portion, has been long applied, the circular profile is now replaced by a rectangular one, sometimes hollowed out (II, Pl. XXX).

At high speeds, in effect, and with long strokes, the forces of inertia tend also to make the connectin-grods bend in the vertical plane. It is thus desirable to augment their stiffness in that direction.

Q being the maximum effort to be transmitted, the section S at the middle ought to satisfy the two conditions : $T = RS$, $Q = k\frac{\pi ES}{a^2}$, k being a coefficient of safety which, according to M. *Reuleaux* (*) does not exceed in locomotives, from 1,5 to 2.

(*) *Der Constructeur, 3nd edition; translation by MM. Delize and Mérijot*, Paris, 1873.

As to the enlargement of the middle portion, it is generally disappearing. According as the velocity increases, in effect, the section of greatest strain leaves the middle and goes up towards the big end, and the enlargement is continued as far as the latter (II, Pls. XIX, XXV, XXVIII), which renders less abrupt the junction of the body with the end, the height of which having for starting point the diameter of the crank-pin, is very great in powerful engines with inside cylinders. (II, Pl. XXX.)

The ordinary key is advantageously replaced (Pl. VIII, *fig.* 14) by a wedge *c* applied against a skew-face of the bearing, the tightening of which is regulated by a screw with a fixed axis *v* (sometimes horizontal for the small ends) and the movable nut of which is the wedge.

The arrangement of the apparatus for adjusting the bearings is however one of the details which are purely technological, which we must pass by. The condition which this adjustment ought to fulfil is not to modify perceptibly the length of the rods from centre to centre, and consequently the position of the piston and the free spaces, without having recourse however to too complicated arrangements, such as the application of double keying (*Bury's* connecting-rods ends)(*). Let us add that, in stationary engines at the present time, no space is left between the edges of the two brasses which take the crank-pin, so that these edges have to be filed in order that the wear may be made up by tightening. For locomotives, it is more prudent to keep in reserve the means of tightening a brass immediately, at need.

For engines with outside cylinders, with reference to the wheels and to the parts of the valve-motion, the brasses and the adjusting apparatus are placed, for the big end as well as for the other, in a recess in the enlargement done in the forging. For inside cylinders, the big end being unable to be slipped over the axle, is terminated either by an enlargement to which is fixed a chape taking the two brasses (II, Pl. XXX), or by a fork (II, Western of France, Pls. XXXIV and XLI), and the joint is made by a cross-beam fixed by nuts and check-nuts.

The solidity of the connection of the connecting-rod with the crank-axle is of paramount importance. Thus many builders have, with this object, accumulated all the means : simple keys, keys with talon, bolts-pressure, screws etc. Perhaps there was therein an excess of precaution. *Stephenson* was content to fix the chape to the connecting-rod by nuts and check, nuts, without any disjunction resulting and connecting-rods falling down,

(*) *Der Constructeur*, 3rd *edition*, *translation by MM. Debize and Mérijot*, p. 537.

which might, assuredly, cause serious accidents. It is not less true that the complication habitual enough, the bulk and the weight of the big ends, constitute an objection of a certain value against inside cylinders. With the exception of the smaller dimensions on account of the reduced diameter of the crank-pin, the big ends of connecting-rods are sometimes similar to the preceding ones, that is to say, forked, notwithstanding the outside position of the cylinders. It is so when the parts of the valve-motion are outside relatively to the motor pieces, the eccentric sheaves being then keyed on to an appendix *a* (Pl. VIII, *fig.* 16) of the driving-pin *m*, brought by a counter-crank into the continuation of the axis of the axle (II, Pls. XXV and XLIII — Northern of France, *Crampton's*, Eastern of France, Charentes line; Southern of Austria eight-wheeled engines, etc.).

Let us cite, on this subject, a detail of construction of the engines delivered by *Sigl* to the *Sud-Bahn* (*Vienna* Exhibition). The cylinders and the frame are outside, and consequently the cranks M brought on to the ends of the axles; the parts of the valve-motion are placed between the frame-plate and the parts of the driving machinery, and the eccentric sheaves *e*, *e'* (Pl. VIII, *fig.* 15) forged in one piece with the crank. Objection may be taken to this latter arrangement, as to all those which combine several organs in one, to enhance the consequences of a partial fracture. It has also against it those which prefer the independence of the two gears in order to keep in reserve the modification of the valve-motion by acting upon the angle at which the two sheaves are keyed, and particularly of the sheave of backward gear.

197. *Coupling-rods.* For coupling-rods the maximum of depth of section is always at the middle. The coefficient of safety is greater for these rods than for the preceding ones. A difference of diameter between the two wheels attached together by a coupling-rod subjects in effect, the latter to considerable additional strains. Thus M. *Reuleaux* has ascertained that 2 is in this case a minimum. It is necessary besides, in order to determine the dimensions of these rods, to consider the engine not only *drawing*, under the action of the steam, but also, if there is occasion, a *holding on* under the action of a break with blocks applied often to a single pair of wheels, the hinder one. We shall return to this point.

The more elongated form of the rectangle may besides be well grounded in this case, by abrogation of the principle which excludes the flexure of the parts compressed, by the utility of a certain flexibility in the horizontal plane, which facilitates running through curves; the less stiffness

of the rods offers less opposition to the slight elastic deformations of the guard-plates, and of the frame itself.

Thanks to very careful fitting of the cranks, the breakages of coupling-rods, which some engineers were afraid of for high speed engines, are very rare. On the Northern of France, one of these rods broke at three points, and the intermediate part went right through a carriage without hitting any one. This is without doubt an example almost unique, of a multiple rupture, except perhaps in case of a collision on the line.

§ IV. — Slides.

198. It is desirable, in order not to exaggerate the work absorbed by the working of this important organ to limit its dimensions, and its maximum travel. In order that a slight displacement of the slide should uncover a sufficient section of the ports, the form of a very elongated rectangle is given to these latter.

Double slide. The surface pressed by the steam can be reduced by the use of two small slides solidly attached, which allows the distance between the extreme ports to be increased on the face, and consequently, the volume of the conduits, and the void spaces, to be decreased. But this complication, applied formerly (*Jackson*, *Hercule* and *Antée*, of the Saint-Germain railway, Pl. VIII, fig. 17), has disappeared, in spite of the simultaneous increase in the dimensions of the engines and of the pressure, on account of running with the greater amount of expansion and of a more exact appreciation of the part, very useful in reality, performed in that case by large void spaces (146, 176, 183).

Length of the slide. The distance L between the extreme edges of the ports being given, the length of the slide follows; it is equal to L plus the outside laps. But the length L is often too great. It is evidently sufficient that the slide, at the end of its maximum travel, should still uncover the central port by an amount equal to that of the extreme ports; all excess, useless from the point of view of the exhaust of the steam, increases in pure loss the length and the resisting work of the slide.

For slides as for segments of pistons, it is desirable to bring the wear upon them rather than on the port-face. This object is agreed on, but not the means of effecting it. On some railways, the slides are in gun metal; in Belgium, the alloy is formed of: copper, 82; tin, 17; lead, 1. Elsewhere, on the Eastern of France for example, gun metal is absolutely prohibited

and cast-iron only admitted. These divergencies are explained by the great variety in the nature of cast-iron, and of gun metal. The condition is almost always that the cast-iron of the cylinder should be harder than the metal of the slide. The *antifriction* metals (for example: copper, 15; tin, 25; lead, 40;) often applied in lining the brasses and almost always to the eccentric belts, are employed also for gun metal slides, but never under the form of continued lining: they fill cavities sometimes cylindrical, and normal to the face, sometimes and oftener, in the form of long grooves cast on the slide.

These grooves are often (fig. 18) 0.32 inch wide at the bottom, and 0.47 or 0.49 inch at the top, so that the proportion of the two elements: anti-friction metal and gun metal, varies a little with the wear. Before casting, the surface of the grooves is tinned. The partisans of this mixed surface pretend that the mean friction is reduced; the white alloy, softer, wears out quicker and goes off, the gun metal then alone bearing, wears more in its turn, until it has got to the level of the alloy, and so on altogether, the opinions are too much divided from want of precise experiments, for it to be decided whether this addition reduces the friction or not, prolongs or not the duration of the slides and of the port-faces.

Bronze ought to be preferred to cast-iron, when the port-face, worn out, is replaced by a plate brought on in cast-steel, which permits its thickness to be reduced. The friction of a cast-iron slide would in that case be very great.

199. *Reduction of the throttling of the ports to admission.* We have seen (175, 176) that for large amounts of expansion, the slide only uncovers for admission a small fraction of an inch; and for very large amounts of expansion, only a slit is opened, so to say. There is thus effected, in the passage from the steam-chest to the cylinders, an unproductive expansion, a fall of pressure which causes the benefit from the high pressure in the boiler to be partly lost. Experience proves, it is true, that this fall is less than was supposed, and notable, only at high speeds.

It has for a long time been endeavoured to uncover, for small travels of the slide, larger admission-openings. Amongst the contrivances imagined for this object, the most, or, more correctly speaking, the only one in vogue (and even then only in Germany and Austria), is the slide with a passage, due to M. *Irick*, the engineer of *Kessler's* works, and which M. *Bréval* proposed to devote to the production of expansion by a special valve (182).

This is the principle: let (*fig.* 19 *a*), $A\alpha\beta\gamma Bn$ be an ordinary slide with

laps; let us suppose it, for greater simplicity, to have constant leads, (*Gooch's* motion), and let us consider it in the position which corresponds to the commencement of admission at A (direct stroke of the piston).

The length of the port face is reduced in such a manner that the slide, in this position, has already passed over the edge of the face, by a certain length mn. Starting from the point m, let us take a small distance mp, from 0.30 to 0.40 inch, and let us imagine the slide traversed in the direction of its length, by a channel, the rectangular section of which has for sides mp and the large dimension of the ports, and ending on the other band of the slide with a symmetrical opening; the admission commencing at A, commences at the same moment at m, and while the slide runs through the length $p'\ q'$, the section of introduction of the steam at l is doubled. The advantage is thus applied to the whole admission, if the travel of the slide is such that p' does not exceed q; for a greater travel, the supplementary admission diminishes and even ceases, but then the direct orifice of introduction has become large enough.

The interval between the edges $q'\ r'$ of the ports ought evidently to be sufficient so that the slide being at the extremity of its maximum travel, the orifice of the channel should still end on a full part of the face, and not open into the central port.

Fig. 19, *b* represents the form given in execution to the slide with a passage.

The good effects which ought to be expected from this ingenious modification have not been established in a very authentic manner. Such is at least the statement of the fifth technical meeting of the German railways; neither economy of fuel, nor, as more immediate effect, increase of the mean pressure during admission, have been recorded.

Let us add however, that in the opinion of some engineers, who make use of the slide with a channel, it allows the section of the ports to be reduced to $\frac{1}{20}$ of the area of the piston, instead of the ordinary from $\frac{1}{15}$ to $\frac{1}{12}$, and even at the present time $\frac{1}{10}$. That is something, because the surface of the slides is thus reduced and consequently the work absorbed by their working.

In any case, the advantage gained is slight enough, and the most remarkable consequence of the application of M. *Irick's* slide appears to us to be an indirect confirmation of the little real weight of one of the most serious

objections in appearance, raised against large amounts of expansion by a single slide : the *wire-drawing* of the steam.

Another slide, called *Hanger's*, attains the same object as the preceding one, by an analogous arrangement, but less simple. It is therefore useless to describe it.

200. *Equilibrated slides.* — The work of the friction of the slides which varies, at the same time, everything else equal, with the degree of admission and the lubrication, is considerable in the powerful locomotives of the present day. This point belongs to the useful effect of the engine, which will be the object of a special investigation. It will thus be a question here only of the endeavours made to reduce the mean effective pressure.

Before examining these, let us mention another means of arriving at the final object : the reduction of the work absorbed by the motion of the slides. It is a question in this of the arrangement, often tried, but without success (II, 79) for the journals, that is to say of the substitution of rolling for sliding, or more correctly speaking, the reduction, by the interposition of rollers, with axes of very small diameter, of the distance run through by that sliding. If for slides, this means appears to be indicated by the much greater value of the coefficient of friction, it appears at the same time hardly compatible with the absence of leakages under their edges. It is however much in use in the United States. The engine exhibited at Paris in 1867 by M. *Grant*, offered an example of it. The slides ran on very hard rollers in steel, exactly flush with the port face. This application seems to prove that the means in question is not so impracticable as would be thought at first sight. However, no European builder has hitherto followed the example of the Americans.

M. Jobin's slide. It is easy, in principle, to withdraw the slide from the pressure of the steam. Every one knows that *Watt's* D slide was so. Thus it is nearly to *Watt's* slide, but without reversing the admission, that M. *Jobin* had returned in a type tried in 1858 on the Eastern of France. *Figs.* 20 and 21 represent the slide with the triangular profile adopted by the inventor. This D slide is, as is seen, surmounted by a cap tightened up against the cover, of the same form, of the box. The steam, introducing itself between the slide and its envelope, the pressures balance, but by introducing a new friction, under the best conditions of lubrication, it is true. M. *Jobin's* arrangement is theoretically satisfactory, it takes into account the position of the slide relatively to the ports; but after lengthened trials on three locomotives of the Eastern of France, it has disappeared,

and probably never to return. The economy of fuel was nil, and the net results were confined to the drawbacks of a notable complication and troublesome maintenance.

Compensator. Among the expedients of this order, the simplest is the compensator, a frame in wrought iron, placed between the back of the slide and the cover of the box, and which thus withdraws from the pressure of the steam all that part of the surface of the slide which it takes in. This ring, ordinarily elliptic, may be fixed, either to the cover, or to the slide. It is ordinarily so to the latter, and rubs on the other. The difficulty is always to obtain intimate contact, with a slight amount of tightening up, without which the risk would be run of losing nearly on one side what is gained on the other.

The compensator possesses besides, like the preceding apparatus, the drawback of rendering the slide fixed, so that it cannot be raised at need to let out the water accumulated in the cylinder; so that the application already made, but admitted to be useless, (188) of safety valves to the cylinders might then become necessary. The compensator is hardly ever applied excepting to the large slides of marine engines.

Slide with holes in the back. — An arrangement which presents itself to the mind, consists in suppressing partly, or even totally, the back of the slide, reduced to its periphery which in this case rises up to the lid of the box, well fitted, exactly parallel to the port face and on which it rubs by its section. The exhaust is then effected, not by a twisted conduit, opening on to the port face, but directly by an opening in the cover, and the edges of which the outside of the slide ought never to pass.

This slide, equally in use in the navy, has also been tried in locomotives by M. *Desgranges*, who applied it in 1851 to an engine on the *Boulogne* and *Amiens* line, and obtained the contact by forming the inside of the slide, (*fig.* 22) of two frames k, k' which fitted one into the other, with the interposition in the groove, of a steel spring, or india rubber ring.

An analogous arrangement, tried in Hanover, gave at first, results which appeared very favourable; according to M. Prüssman the economy of fuel exceeded six per cent; which did not prevent the slide with openings in the back from soon disappearing.

Suspended slide. — Another method consists in suspending the link (*fig.* 23) by a rod with a double articulation b to a piston P movable in a cylindrical appendage applied to the cover of the valve-box. This apparatus, known in the navy under the name of *sucker*, was adapted five and twenty years ago to several locomotives in Brunswick, introduced also into Hanover at a

time when an abnormal wear of the port faces and the slides occupied great attention, it was not long in being condemned there also.

This opposition of the steam to itself certainly seems very logical. But, in locomotives still more than in any other engine, the introduction of new organs subject to derangement, to interfere with the regularity of the service, to bring the engines oftener into the sheds, represents a number of disadvantages which could only be compensated by a considerable economy of fuel, seeing that that alone is in question here. Now, that which the sucker procured was very slight, if even it existed at all.

This is sufficient to settle the question; but it must not be forgotten, further, how much space is measured in the locomotive, how much the addition, the simplest in appearance often meets with difficulties. Thus, in the actual case, the projection of the pipe above the cover of the box is of itself a grave objection, so much the more that the length of this pipe ought to be considerable in order to reduce the obliquities of the connecting rod.

M. *Walker* proposed to get rid of these obliquities by forming the port face and the slide itself, of portions of cylinders having for axis a horizontal line passing through the point where the connecting rod is fixed; but this was entering into complications much more serious than the drawback which was thus avoided.

Of all the attempts made to reduce the effective pressure to which the slides are subjected, a simple one has survived, thanks to its simplicity, on the Eastern of Prussia; but it only attains the object in very restricted proportion. It consists (*fig.* 24) in reducing to the strictly necessary (that is to say, as much as solidity and the leaks to be avoided, allow), the parts m n, m' n' the portions of the face outside the ports; when the slide passes over one of the edges, n or n', the pressures balance on the projecting portion of the band. But that only takes place, in general, on one side, solely towards the extremities of large travels, and not at all for small ones, which only involve however, by their very smallness, a reduced amount of work. The *Graffenstaden* engine (II, Pl. XX, *fig.* 1) offers an example of the port face thus reduced to a minimum, that is to say to the sum of the ports, and of the necessary thicknesses of metal.

Let us remark, in passing, that the port face ought always to present a recess at the two ends, so that the slide, at least when it is at the end of its large travels, may exceed a little the edge of the table. Thus is avoided the formation of two flanges on the latter by the wear.

Valve-rod. The valve is never solidly connected to its rod. The latter

guided at the two ends, a point always indispensable, especially when the port face is not very nearly horizontal, supports the slide when it is vertical (II, Pl. XXXIII), or placed under the cylinder (II, Pl. XLII, *fig.* 3). The two parts of the rod are forged in one piece with a frame which takes the projection of the slide, but without pressing the latter on to the port face (*fig.* 24, II, Pl. XXXIII, *fig.* 2, and Pl. LV, *fig.* 1). It is the pressure of the steam which realizes this application much more certainly than the frame could do it, in case the fitting was defective, and the wear notable. The slide ought besides to lift a little, in order, at need, to give a passage for the water and compressed air. In order to prevent *knocking*, a spring is often placed between the frame and the slide. However, this springs breaks sometimes and its fragments may get into the cylinder; it is now generally abandoned, when the port face is horizontal or little inclined.

The frame is at times replaced by brackets keyed on to a continuous rod, and which take hold of the slide, always leaving it a certain play normally to the face. (II, Pls. XXVI and LXXIV).

The continuation of the rod often carries on the outside, more or less near its connection with the link-stud, an adjusting screw (II, Pl. XX, *fig.* 1, and Pl. XXVI). This means is convenient; some engineers reject it however and not without grounds : the drivers sometimes make use of it rashly, without taking the trouble to open the cover of the valve-box, and run the risk thus of increasing the defects they are trying to remedy.

Working the valve-motion. The suspension-rod of the link and that of the movable spindle in *Gooch's* and *Allan's* link-motions, were at first, and still are, to the present day worked by means of a lever with a bolt (II, Pls. XIX, XLVIII, etc.).

But this lever is often (not however as often as it would be desirable) replaced by *Kitson's* screw, applied by this builder as far back as 1855. We shall return to this point (212) when treating of reversing and running with counter-steam, a subject with which it is intimately connected.

FIFTH BOOK

MEANS OF DESTROYING VELOCITY

AND

OF MODERATING IT ON INCLINES

CHAPTER I.

PRELIMINARY CONSIDERATIONS.

201. It would be, in certain respects, natural to place here the investigation of the resistance of trains. But it is more in conformity with our plan to group together, as we have stated (II, 189) the means of producing velocity and of destroying it, the more so as the locomotive performs also, in the second case a main part.

In principle, bringing means of stoppage into play only requires a motor work independent of the duration of their action, that is to say of the total resisting work to be developed. The first may be even taken by means of various contrivances from the *vis viva* of the train. The resistance opposed, either to the inertia of the train in motion, or to gravity, is usually, as in ordinary vehicles the friction developed by a pressure variable at will, between parts sliding the one on the other. In a vehicle the sole parts endowed with a relative movement are the pairs of wheels; it is then on these that the pressure is applied, and at the points where the velocity is a maximum, that is to say at the rim; the blocks may be also pressed against the rails, which comes to the same thing as the distance run through by the friction; and the work of tightening and bringing into play is furnished, either by the fireman and the guards, or, but rarely hitherto, by the contrivances to which we have just alluded, and which will be pointed out farther on.

All these systems, founded on friction have a common and serious drawback, the rapid wear, either of the tires or of the rails, or even of both. The

working of brakes by the guards, each acting ordinarily on a single vehicle, is however an expedient at once costly and precarious, on account of the staff it requires. The whistles by which the driver calls for the brakes to be put on, do not always find the men attentive and ready to obey. The guards fall asleep, or even take advantage at times, of the lateral communication by means of the foot boards and hand rails, with which passenger carriages are provided to (II, 26) to leave their post. Even under the most favourable circumstances, the condition of an intermediate always causes an inevitable loss of time. The locomotive, which is itself a vehicle, and which is adapted for the application of the same means of stoppage as the carriages, possesses in addition, when it is in steam, the property of acting as a powerful brake, and of escaping the evil common to the others, that is to say the rails and the tires are not subjected, unless in the case of an accidental slipping, to any friction.

This special brake of the locomotive allows of returning into the boiler, under the form of heat, either the *vis viva* of the train, or the work of gravity down inclines, while with ordinary brakes the heat developed by the friction passes off into the atmosphere (1) ; at the same time, truly speaking, this return of heat to the boiler is scarcely more than a theoretical advantage.

202. *Three cases to distinguish. Insufficiency of the resistances of the train.* The means of destroying and moderating the velocity ought to be regarded from three points of view :

1st. Unforeseen stoppages in front of a signal indicating an obstacle, and, the case arising in sight of the obstacle itself not signalled, such as a slip of earth, on the permanent way, etc.;

2nd. Normal stoppages at stations, provided for by the time-bill;

3rd. Reduction of speed on the descent of long and very steep inclines, to a regulation figure lower than the speed which the train would take of itself, the regulator being closed, under the action of gravity.

A first means, very generally insufficient, consists in the simple suspension of the action of the motor, by the closing of the regulator.

P being the gross weight of the train; P′ that weight increased by 0,54 of the weight of the turning parts; $p+qv^2$ its resistance at the decreasing velocity v; o the resistance of the machinery, the regulator being closed; $\frac{1}{i}$ the inclination of the section, we have, dv, being the diminution of the velocity which corresponds to an element of distance run dl, the sign

+ referring to an up gradient and the sign — to a down gradient;

$$\left(p + qv^2 + o \pm \frac{P}{i}\right) dl = -\frac{P'}{g} v dv;$$

whence

$$l = -\frac{P'}{2gq} \text{log. n.} \left(p + qv^2 + o \pm \frac{P}{i}\right) + C,$$

and V being the velocity at the origin, that is to say for $l = 0$,

$$l = \frac{P'}{2gq} \text{log. n.} \frac{p + qV^2 + o \pm \frac{P}{i}}{P + qv^2 + o \pm \frac{P}{i}},$$

and L being the distance run, up to stopping, that is to say for $v = 0$,

$$L = \frac{P'}{2gp} \text{log. n.} \frac{p + qV^2 + o \pm \frac{P}{i}}{p + o \pm \frac{P}{i}} \qquad (1)$$

As we have remarked (148,3rd), if the closing of the regulator reduces the resistance of the machinery, it introduces on another side a special resistance. The piston acts as a brake by the compression of the gases which it has drawn in ; but it is necessary, as we have seen, to reduce greatly that effect by giving the slide its maximum travel. Mr *Bramwell* cites (*) an observation of the distance run up to stoppage from the moment of the closing of the regulator, by a train, the engine of which was provided with an indicator. The mean resistance per ton of train gross was 22 lbs of which 3.5 lbs was supplied, as resulted from the indicator diagram by the compression in question, but it was not said whether the lever was at the notch of full steam.

Without stopping for numerical applications without interest, it is clear that the value of L given by equation (1) is only sufficiently reduced when the quantity $\frac{P}{i}$ added to the two terms of the fractional expression $\frac{p+qV^2+o}{p+o}$ is positive, and great enough, that is to say on ascending steep gradients. On a horizontal, and with greater reason on an incline, the resistances proper of the train are absolutely insufficient; others must be added, often very great, obtained, for example, by skidding, or nearly so, a certain number of wheels. If the fraction of the weight P thus skidded is $\frac{P}{K}$, it intro-

(*) *Minutes of proceedings* of the Institution of Civil Engineers, 1871, vol. XXXI, page 388.

duces a resistance $\frac{f\,P}{K}$ (f being the coefficient of friction) which has to be added to the two terms of expression (1). The length L run through before stopping being given, equation (1), gives the weight to be stopped $\frac{P}{K}$.

The same expression would apply in the case of running backwards on account of the breakage of a coupling; P designating in that case the weight of the portion detached, $\frac{P}{K}$ the fraction of this weight to be stopped, V the backward velocity which a delay in the action of the guards would have allowed to have set up, and L the distance at the end of which the stoppage should be obtained; the distribution of the brakes should be fixed from this point of view especially if there were no engine behind; it might besides itself be insufficient (II, 369).

The driver ought everywhere and always to be the master of his train. There should be then, at his disposal, all possible means of slackening and of stopping, as he directs the motive power. Better placed than any other person in the train for appreciating the necessity of stopping more or less promptly, he ought to have directly under his hand some powerful means of stoppage, if not indeed the whole of those possessed by the train in virtue of its mass, of its velocity, and of the section of the line.

This latter problem has for a long time been under investigation, and we shall return to it after having examined the means of stopping now in use, and particularly those which are applied to the engine.

CHAPTER II.

COUNTER-STEAM

The driver has in effect, at his immediate disposal, a powerful brake, the engine; the more powerful, the more of its weight is adherent, whence results, let us remark at once, a new and one of the most decisive arguments, in favour of the application, more and more frequent (II, 249, 253, 257) of engines with four wheels coupled to high speed trains, which from that very fact require most powerful means of stopping.

So as to proceed in order, let us study first this special brake, its mode of action in each of the three cases that we have distinguished (201); and let us commence by the least frequent, but also that which most directly affects safety, that is to say the stoppage to be most rapidly produced in the face of a signal to stop, tardily made or perceived, or of an obstacle occurring on the line.

§ I. — Principle of counter-steam.

203. The current conditions of its work require that the locomotive should *reverse*. Station operations, a train which lies by to allow a faster one to pass (which on railways with two lines is always done by shunting), a train which, having passed the normal point of stoppage in a station, is obliged to come back thereto, constantly necessitate backward motion to be brought into play at every moment. Often indeed engines work tender foremost; others, like the *Fairlie* engines (II, 362) are symmetrical and run indifferently in either direction, without being turned.

This faculty possessed by the locomotive of running the train to which it is coupled backwards, as well as forwards, may be also applied, either to the stopping, or to the slackening of running trains. Let ut suppose at first a train on a level. If, after a stoppage, the driver reverses the action of the steam by placing, for example, the valve-motion for backward gear at the point at which it was for forward gear, starting by reversing the rotation of

the wheels takes place immediately, and the train is backed by an effort equal to that which determined the direct movement.

If the train is running, the *partial* reversing of the steam may, in certain cases, as we shall soon see (206 and foll.), produce effects quite other than those which are ordinarily supposed, that is to say, it may reduce simply the effective mean effort of the steam on the pistons, *without changing their direction*. But, even at the end of the stroke, this reversing does not produce immediately that of the rotation of the driving-wheels. The *vis viva* of rotation accumulated in these wheels and the parts attached thereto (driving machinery, coupling-rods) must first be extinguished, and the friction of the tires on the rails overcome. Until then, the piston, carried on by the forces of inertia of this partial system, drives the steam before it, gradually losing its velocity. The *vis viva* accumulated in the driving-wheels and the machinery being a very small fraction of the total *vis viva* of the train, is extinguished the first. Then, if the reverse admission is great enough for the mean effective effort of the steam referred to the circumference of the driving-wheels to surpass the friction on the rails, the rotation changes direction. There is thus a second period, characterized by this fact that the train continuing to run forward with a decreasing velocity, the driving and coupled wheels turn in a contrary direction; and the engine then exerts a *pushing* effort against the train, contrary to the drawing-effort which is applied thereto, before the reversing of the valve-motion, but not equal for the same *notch*, because the effort, in one direction as in the other has the adhesion for limit, and because the rotation, in a direction contrary to the movement of translation, that is to say, slipping, has the effect, every thing else equal, of greatly reducing the adhesion.

Abstraction made of this influence of the slipping, the pushing effort is thus the same as if the driving-wheels were simply *skidded*, the resisting work of the sliding on the rails no more than balancing the motor work of the steam upon the piston. Skidding, if it could be carried out and kept up, would suppress all expenditure of steam; but it would always be *slipping*, and under conditions more injurious even than with rotation, because the latter, at least, wears the tire uniformly and does not produce flat places. But prolonged slipping, under one form or the other, ought to be excluded, not only because it lowers the coefficient of friction, and consequently the limit of the pushing effort, but also because it is destructive for tires and rails.

This consideration is at the same time of very little importance in the particular case which occupies us, because the period of slipping is very short,

the driver having, above every thing, to pull up in the promptest manner possible, without preoccupying himself with measuring effects or of avoiding drawbacks then quite secondary. Taken by surprise with a signal to stop or an obstacle on the line, especially a train in front of him, the driver reverses or *does his best to reverse* the action of the steam as promptly as possible, to put his lever right over, and to fix it there, and as the limit of the amount of pushing depends on the adhesion, the fireman lets sand down, which retards the reversing of the rotation, and increases at the same time the effect of the counter-steam and that of the brakes of the train.

Let us remark at once, in order to avoid a very usual confusion, that the two improvements which the regular use of counter-steam allows, must be distinguished from one another : the one, common to the three cases (the substitution of the screw for the lever) (212), is in reality the only one which affects that which we are considering at this moment; the other (the injection under the slides) (219) applies to the two other cases.

§ II. — Difficulty of reversing the valve-motion. Its causes.

204. Formerly, reversing during running, by working the lever, was an easy operation. The engines were not powerful, the slides had small surfaces and short travels, the pressure was low, and the velocity very moderate.

These conditions are quite changed. The parts to displace vertically, *Stephenson's* or *Allan's* link or eccentric rods are of course balanced; *Gooch's* link only requires the displacement of a simple spindle. However, working the valves, in powerful engines, had become very difficult, very uncertain, even dangerous. If the driver succeeded in giving the lever the necessary displacement, very often he could not fix it in the new position ; set free, the lever was drawn over towards the position, at the end of the stroke, in forward gear.

The difficulty varied more or less with the type of valve-motion ; but it always existed. With *Stephenson's* link, it can be reduced for forward gear by adding to the counter-weight (as in the engines of Mr *Gouin* cited by Mr *Balguerie*) (1), but by increasing it for backward gear.

The primary cause of the obstacle to the reversing of the lever is the resistance, under the pressure of the steam, to the displacement of the large

(*) *Bulletin de la Société d'Encouragement*, 1874, vol. I, p. 84.

slides. As to the taking over of the lever unfastened, it has been endeavoured to be explained by the rotation itself of the driving-axle, tending by the friction of its sheaves on the clips to take over the eccentric rods and the link and thus bring them to the end of the stroke in forward gear.

This explanation, true only, but completely insufficient for *Stephenson's* valve-motion with *straight rods* (151) is false for *crossed rods*, with which the passage from *forward gear* to *backward gear* is done by the lowering of the link so that the friction of the sheaves on the clips acted on the contrary in the direction of the displacement to be imparted to the pieces; and it is not less erroneous for *Gooch's* (152) and *Allan's* (153), in which the link is suspended from a fixed point.

The cause which always preponderates, and is frequently unique, in the case of the lever being drawn over, is the inclination of the link. If the link (or more correctly speaking, its chord) were normal to the valve-rod, the effort transmitted by the first to the second would not tend to set up any relative movement between them. But on account of their mutual inclination, variable at the same time, at each instant, with the angular position of the driving-shaft, these two pieces tend to slide the one over the other.

As long as the lever is locked, this sliding, this relative movement of the link-stud, is impossible, or more exactly, it is reduced to that which is the necessary consequence of the figure itself and of the connections of the articulated system, that is to say the *disturbance* (152; 108, tables). But as soon as the unlocking and freedom of the lever have caused one of these connections to disappear, that is to say comes freely into effect, affecting only the link, seeing that the valve-rod and the link-pin which drives it are guided, and fixed according to the vertical. The valve-rod is alternately drawn and pushed; the effort Q which is applied to it by the link, changes direction at each end of the travel of the slide. The sliding, or the tendency to slide of the link on the pin would be thus exerted, sometimes in one direction, sometimes in the other, from above downwards and from below upwards, if the inclination to the vertical of the inclined plane, which the link forms, did not itself change its direction periodically. We have seen (162) what is the expression of this inclination β, supposed small enough for $\cos\beta$ to be taken $=1$. If, in order to content ourselves with an approximation sufficient for the point which we are investigating, we suppose the eccentric rods long enough for the terms which have b as divisor to be neglected, this expression is reduced to :

$$\sin\beta = \frac{r}{c}\cos\omega\sin\alpha.$$

β changes sign then nearly at the same time as sin α, that is to say at the two extremities of the stroke of the piston.

By calculating the values of the component which tends to determine sliding, Mr *Balguerie* (1) has ascertained that, on account of the correlation of the simultaneous directions of the force Q, and of the inclination β, this component acts, during the greater part of the revolution of the axle, in the direction of the carrying over of the link towards the position of forward admission. It only changes sign for a very short time, which explains how the driver succeeds sometimes, with an ease which surprises himself, in reversing, which is ordinarily so difficult, if not impossible to do. This is no caprice of the engine; it is simply that the driver, by a lucky chance, happened upon an angular position of the shaft, very near that which corresponds to the change of sign of the component of the sliding. We see also how the operation is more difficult, the greater the velocity; this is because the positions of *easy reversing* are then so fugitive, so instantaneous, that the driver has not the time to seize and take advantage of them.

The intensity of the component of the sliding being nearly proportional to the sine of the inclination of the chord of the link to the vertical, there results from this, especially in engines where the lever has been kept, a further argument against the arrangements which conduce to notable obliquities of the link (169).

The difficulty of the operation, the uncertainty of success, at times (but only when the play at the joints was excessive) shocks given to the mechanism by too sudden reversing, lastly some examples of injuries caused by the sudden recall of the lever, which could not be locked (and inclined wrongly towards the back for forward gear) (214), explain the repugnance entertained by drivers to having recourse to reversing the action of the steam. They only do it as a last extremity, unless at low speeds; in which reversing, convenient for the precision of working, is easy, but without importance from the point of view of safety.

205. *Closing the regulator.* The obstacle to the displacement of the slide and the link being the considerable pressure to which the former is subjected, it is sufficient, in order to make it disappear, to remove that pressure, by closing the regulator; which at the same time greatly reduces the resistance proper due to the inclination of the link, as that resistance is proportional to the reaction of the slide-rod. But if this expedient, which has be-

(1) Article quoted above, p. 73.

sides become necessary, renders the working safer, it renders it also slower. It is necessary in effect: 1st, to close the regulator; 2nd, to reverse; 3rd, to open the regulator again. These three operations, even supposed to be done without the slightest hesitation, and with success, require at least 10″, and during that time, the engine is rushing over the ground at high speed. Often at the same time, the driver, not succeeding, on account of his hurry, in fixing the bolt of the lever in the notch of the segment, keeps trying and struggling before he can put the steam on.

§ III. — Running at the *dead point* of the link. Persistence of the *motor* work, for a certain extent of the *reverse distribution*.

206. *Tractive effort on the pistons, the distribution being at the dead point.* The moment is come to dwell on this point, already indicated farther back (150, 151) and the investigation of which we reserved.

It is ordinarily supposed that one of the halves of the link corresponds to *forward gear*, or to *traction*, the other to *backward gear* or to *shunting*, and that its middle is consequently the precise point of the passage from one gear to the other, or of the change of sign of the effort.

It is not so in an engine running, the distribution of which is then put at the dead point, or even reversed in a certain degree.

1st. If the middle of the link coincides with the centre of the slide, for a determinate position of the crank, for example at the commencement of the direct stroke of the piston, this coincidence does not take place during the course of the revolution. The point by which the link takes the guide-block varies; on account of the vertical oscillation of the first, and according to its mode of suspension; this point may belong, sometimes to its upper half, sometimes to its lower half.

With the suspension at the middle, which is the most usual, this relative displacement of the acting point of the link, *or the disturbance*, diminishes with the travel of the slide; and towards the minimum travel, that is to say what is called the *dead point*, it has only a small value which descends even at times to 0.078, and even to 0.039 inch (208, table I). But, abstraction made of this influence, rarely as slight and sometimes much greater with *Stephenson's* link (table III, and particularly, table IV), the movement, parallel to the slide-rod, of the acting point, more or less close to the middle of the link, and consequently the movement of the slide, is not *nil*, and it still distributes. There is admission in this position, at least in well adjus-

ted engines, seeing that there is an admission lead; constant for *Gooch's* valve-motion, nearly constant for *Allan's* valve-motion, this lead has, for *Stephenson's* link, its maximum value if the rods are straight, and its minimum value if they are crossed, when the slide is at its minimum travel. It is then, especially for crossed rods that the admission lead might then be *nil*, or even changed into a drawback, not on one face only, as sometimes takes place with straight rods (208, tables III, and IV), but on both.

There is even with crossed rods, if the angles at which the eccentrics have been keyed on are large enough, and if the valve-motion is symmetrical enough, admission during a small fraction, some hundredths of the stroke of the piston; there is consequently, on its two faces, the three ordinary phases and definitively a work, positive or negative, of the steam on the piston.

If, this work being positive, the corresponding mean effective effort is greater than that which represents the total resistance (machinery and vehicle) of the engine, the engine still draws; if it is smaller, it exerts on the train, not an effort of traction, but of holding back. If equality took place, the engine would be neuter, neither drawing nor pushing. The intensity, and the direction of the effort exerted depend on the pressure in the boiler.

207. *Influence of play in the joints.* The first, if not even the second, depend also on the play of the parts. Some engineers see even in this play, inevitable, but variable, the unique cause of the work which a locomotive can develop working with the lever or the screw at the dead point.

Such is the opinion expressed in the following note by M. *Pascal*, head of the central office of the locomotive department of the Northern of France, and which Mr *Délebecque* engineer in chief has had the kindness to forward to me.

In taking only this cause into account, doubtless real, of very variable influence, and which is only a simple defect of *construction*, geometrical, necessary causes are left on one side : the mode of *suspension*, above or below, of the link, and the *disturbance*. But above all, the pure and simple consideration of the extent of the phases on the two faces of the piston (215) is not sufficient in order to foresee and explain what passes, as to the quantity, and even as to the *direction* of the work, on the *pistons*, in an engine, the valve-motion of which is put at the dead point (or reversed) *while running*. As besides the note in question analyzes exactly the influence of the unique cause which it admits, it will give satisfaction to reproduce it first :

" Let us take a *Stephenson's* or *Gooch's* link-motion, having the angle of

advance of forward gear equal to that of backward gear and in which the link is suspended or guided by its middle, which is the most general case (Pl. VIII, *fig.* 25).

" If the reversing lever be placed at the dead point, that is to say at the mean position between forward gear and backward gear, the examination of the diverse successive phases of the distribution resulting from the arrangement of the organs shows that, theoretically, the engine ought not to be able to move itself either in one direction or the other, although there really is an admission of steam, which varies ordinarily between five and fifteen per cent of the stroke of the piston, according to the lap given to the slide.

" In effect, if the movement of the piston through a complete revolution of the wheels be followed, starting from the dead point M of the driving-crank, it is remarked on account of the symmetry in the valve-motion, as regards the line MN passing through the axis of the driving-axle and through the middle of the link, that to the same position occupied by the slide at the end of the admission, and at the commencement of counter-steam, correspond necessarily the symmetrical positions M′ M″ of the driving-crank, with reference to the axis of the cylinder, and giving consequently the same value to admission and to the counter-steam in part of the stroke of the piston.

" For the same reason, the expansion and compression have the same value as well as the anticipated exhaust, and the exhaust proper.

" As there is an identity between the laws of expansion and compression, it results finally that, in one complete revolution, the motor work is exactly the same as the resisting work. The engine ought not then, theoretically, to be able to run with the valve-motion at the dead point.

" In practice, it is not the same, on account of the imperfection of the apparatus of distribution. In effect, there is always play in the different parts: eccentric clip, articulation of the rods on to the link, link-pin, up to the slide itself, which is free in its frame. The slide being drawn and pushed alternately, it occupies really, on account of this play, different positions for symmetrical positions of the driving-crank, at the end of the admission, and the commencement of the counter-steam. Valve-motions are generally adjusted for the values of the admission, when the slide, running in one direction, just closes the port. When the slide on the contrary, just uncovers the port, running in the reverse direction, it has taken, on account of the play, a drawback variable according to the state in which the organs are kept. The drawback may be a fraction of an inch, and to this new position of the slide corresponds a position of the driving-crank giving counter-steam a value less than that of admission.

" All the valve-motions, adjusted cold on the engines show a value for the admission a little above that of the counter-steam; but when the engine is in work, the pressure of the steam on the slide increases the alternative tension and compression of the organs, which has the effect of increasing the difference of the two values of the admission and the counter-steam.

" This material fact *may give* the explanation of the possible running of a locomotive either forwards or backwards, when the organs of the distribution are arranged in such a way as, theoretically, should neutralize the running.

" A diagram taken from a model in wood of a valve-motion, in which play between the parts had been purposely allowed, gave at the different phases of running at dead point, the values per cent of the stroke of the piston indicated in the following table :

PHASES OF THE DISTRIBUTION.		FORWARD GEAR.	BACKWARD GEAR.
Direct stroke...	1st Admission	14	13
	2nd Expansion	42	43
	3rd Anticipated exhaust	44	44
Return stroke...	4th Exhaust proper	50	50
	5th Compression	43	43
	1st Driving back or counter-steam	7	7

" *La Chapelle*, 31 *May* 1873. "

In fact, for most engines, the work of the steam is positive, and prevails over that of their resistances, so that they draw still when the driver gives the slide, its minimum travel, during running.

In this position no starting would be possible. In almost all the angular positions of the axle there is not, in effect, in that case, any introduction either in the one or the other of the cylinders; and in the most favourable positions, that is to say, when one of the pistons has passed very little beyond the commencement of its stroke, the crank is almost in the continuation of the rod, and consequently the moment almost *nil*. But in running, the dead points are passed over by the inertia, the distribution takes place, and the mean effective effort may still be great enough to maintain, on a level, the normal velocity of a light train, as many drivers know.

As long as there is a *motor area*, an effort of traction, with the lever brought to the dead point, the same effect ought, on account of the continuity, to persist for a certain extent of backward running; the engine ought to continue to pull, although its valve-motion is reversed.

208. Mr *Forquenot*, engineer in chief, has been good enough at my re-

quest, to have a diagram (Pl. IX, *fig.* 1) taken from an engine drawing a light train, and the valve-motion of which was put at the dead point on a horizontal where it took a uniform velocity.

Engine 852 (1875) 6 coupled wheels. Cylinders 1.48 feet × 2.13 *Gooch's* link-motion (Pl. VIII, *fig.* 26)
Velocity 18.7 m. No. of scale 8 atms. in boiler.

Travel of the slide	maximum....	4.72 inch.	Laps	outside...	2.36 inch.
	minimum....	2.76 »		inside....	0.04

The travel of the indicator piston being 7.08 inches, and that of the piston of the engine being 2.13 feet, the 0.35 in, admission corresponds

to $0.35 \times \frac{25.59}{7.08} = 1.28$, or 5 % of the stroke.

Fig. 2 gives from tenth to tenth of the stroke, for forward gear with direct admission, the theoretical effects of the steam referred to the circumference of the wheels, that is to say the mean effective pressure deduced from diagrams with closed curves, doubled and multiplied by $\frac{2l}{\pi D}$. The real effort on the coupling-bar is the effort thus calculated, less the resistance of the machinery (and vehicle) of the engine.

The annexed table gives for all the notches of forward and backward gear, the phases of the distribution of that engine : the diagram (Pl. IX, *fig.* 1) corresponds the hiatus left by the column of the *dead point.*

We reproduce at the same time, in table II the elements of the distribution of another series (1 to 32), equally with *Gooch's* link, and with independent wheels. *Fig.* 3 (Pl. IX) reproduces the diagram taken from N° 17 belonging to that series, for the eleven notches of forward gear, the effective pressure in the boiler being 102,405 lbs. for a square inch and the velocity being 15.5 miles an hour.

With *Stephenson's* link with straight rods, running at the dead point, or at the minimum travel would give equally useful work provided the leads are nearly equal on the two faces, at least for small travels of the slide. This is what takes place for the series 980-964 (cylinders of 25. 7 inches by 17.72 inches, angles of eccentric sheaves 26° and 28°, laps 1.18 inch and 0,017 inch, maximum travel of the slide 4.72 inches) of which table III gives the distribution.

It is different with the series 983-987 (keying 11° and 11°, maximum travel 5.90 inches) in which the lead on one side reaches 0,24 inch, while it is negative or *nil* on the other, so that at the dead point there would only be admission on one side (table IV).

This last valve-motion is however defective; with straight rods, a slight

drawback may strictly speaking be allowed for the admission with very large introductions, which are very little used, provided this drawback disappear and be replaced by a suitable advance for the notches most employed. Such is the case for the series 988—994, where a lead appears, on both sides, when the admission is below about 0.60.

But in the series 983—987, the total absence of advance for one of the sides persists up to the minimum travel. This is a serious fault, from the point of view of the normal work; for it was only a question of running at the dead point, that is to say, a particular case, interesting in itself, but of very restricted application.

We see besides how considerable the disturbances are in this type especially in forward gear.

209. If, an engine *drawing* its train successively tender behind and tender in front, that is to say, with the valve-motion in *backward gear*, its minimum travel be given to the slide, the two efforts, more or less different, according to the obliquities (and able in certain cases to be equal, if the valve-motion is very symmetrical), would be in the same direction; we should thus have for this same position of the lever, two contrary effects, forward running, backward running. There is a certain mean region of the slide, which corresponds equally to the two gears; a region not inert, but *neuter*, or indifferent, which keeps up the *direction of running existing* at the moment when the lever is placed in its mean position.

It would be interesting to compare the diagrams taken from an engine drawing thus, its train tender behind, then tender in front, and after putting the lever in the mean position. Engine 852, the valve-motion of which is, as table I indicates, very symmetrical for the two gears, would without doubt give for counterpart of the diagram (Pl. IX, fig. I) a curve differing very little.

In the trials made on the *Hauenstein* incline, M. *Beugniot* (*), kept back the trains by placing the slides, not even at the dead point (travel 2.87 inches), but at the first notch of *forward* gear (travel 3,07 inches,) which would seem at first sight difficult to reconcile with what precedes. But the steam only played in this case a very secondary part; the regulator was only open at intervals, in order to lubricate; the mean admission was extremely slight, and the conditions approximated greatly to those of running with the regu-

(*) Bulletin de la Société de Mulhouse, vol. XXX, page 495.

lator constantly shut, so that the work of compression of the gases drawn in, then compressed during a great portion of the stroke of the piston, prevailed considerably over the very small work of the steam (148, 3 d.).

210. *Experiments on the point at which the mean effective effort of the steam on the pistons changes sign when the valve-motion is reversed while running.* The preceding sheets had been printed, when M. *Forquenot* was good enough (June 1875), to have special experiments made in order to ascertain, at least for one particular type, this mean extent of the link, on one side and the other of its middle, which may, in forward and in backward gear, give an effective effort on the piston in the same direction. These experiments prove that with a valve-motion very symmetrical for the two strokes direct and return, and for the two gears, this *indifferent* portion may be much more considerable than I had supposed. This fact is too interesting for me to hesitate to bring in here the results of these experiments, confided to M. *H. Gerbaud* formerly pupil of the Polytechnic School and of the School of Mines (*Paris*).

Engine 917 with six wheels coupled. Gooch's *link-motion* straight rods.

The minimum travel of the slide corresponds exactly to the zero of the rule.
Admission leads, constant on the two faces : 0,27 inch.

TABLEAU A.

Admission in hundredths of the stroke, at the different notches of forward gear.

NOTCHES.	ADMISSION.	
	Course direct.	Course retrograde.
	per cent.	per cent.
0	11,5	11,5
5	15,5	16,5
10	18,5	21,0
15	21,0	24,0
20	23,0	27,4
25	27,5	32,5
30	32,5	38,5
40	39,0	46,0
50	50,4	55,1
60	59,7	64,6
70	69,7	70,5

TABLEAU B.

Distance of the link-pin to the middle of the link for various notches of forward and backward gear.

NOTCHES.	SUCCESSIVE TRAVELS OF THE LINK.		TOTAL DISTANCES.	
	Forward.	Backward.	Forward.	Backward.
	inch.	inch.	inch.	inch.
0 (dead point)	0	0	0	0
10	14,5	19,0	14,5	19,0
20	15,5	15,0	30,0	34,0
30	19,0	20,0	49,0	54,0
40	14,0	19,5	63,0	73,5
	20,5	20,0	83,5	93,5
	52,5	50,5	136,0	134,0

The distribution is made by a slide with *passage* (197); but, as shown by *fig.* 31 (Pl. VIII), this slide is not arranged correctly. The passage, which ought to commence to admit behind, exactly at the same instant as the edge of the slide in the front has a notable drawback (0,21 inch) to the admission. This circumstance, moreover, was not of a nature to modify perceptibly the difference in the amounts of work applied by the steam to the two faces of the piston.

1 st *trial.*

Engine only, on a level, regulator open, valve-motion at the dead point; effective pressure in the cylinder 99.50 lbs. on the square inch.

1 st. *Forward gear.*

a. Starting. — By increasing successively the admission that is only at notch 20. that the engine starts, *freely.*

admission. . direct stroke 23,0 0/0
admission. . return stroke. . . . . 27,4 —

The admission is reduced.

admission. . direct stroke 21,0 0/0
admission. . return stroke. . . . . 24,0 —

at notch 15 the engine stops; it starts afresh, at the same notch, when the cranks had been previously placed at 45°.

b. Engine sent on ahead. — The valve-motion is reversed, during running :
1 st. at notch 10, the direct movement continues, with a uniform velocity less.
2 nd. — 15, it continues still.
3 rd, — 20, the engine stops.

2 nd. *Backward gear, tender foremost.*
The same effects, exactly at the same notches.

At notch 15 *backward gear*, the link-pin is at a distance from the dead

point comprised between 0.75 and 1.34 inch (table B), or at any rate more than 0.79 inch. There is thus an extent of more than 0.79 inch of the lower half of the link, to which the forward movement still corresponds, previously when that movement exists as the moment of reversing.

The action of the counter-steam does not then commence, or at least cannot really commence until much later than is ordinarily supposed. Even at an already high notch, the reverse admission is far from *holding back*, as is believed; the engine still draws; or more exactly, the effective effort *of the steam* instead of being resisting, is still motor.

2nd *trial.*

Engine coupled to a train which it draws, and then shunts. In both cases, the valve-motion is put, during running, at the dead point, and the indicator gives the diagrams Pl. IX, *fig.* 4 for forward gear, and, *fig.* 5, for backward gear.

We have thus, at the dead point, useful areas differing little, and consequently, effective mean efforts *perceptibly equal and contrary* to the steam on the pistons.

The relative values for backward gear are a little less, but the pressure in the boiler was a little lower in this case (103.11 lbs. instead of 113.07 lbs.), and the areas are very nearly proportional to the pressures.

The difference in the speeds, must it is true be taken into account also. In *forward gear*, the velocity was 14.6 miles; in *backward gear* it had been reduced to a value stated only thus: *station operations speed*, that is to say doubtless about 9 miles an hour; so the line of admission of the diagram approached nearer the line of the boiler pressure.

But without dwelling on these little shades of difference, we see that the almost identical nature of the contrary efforts exerted by the engine, with the valve-motion at the dead point, comes out clearly in this experiment.

3rd *trial.*

1st. The train was run ahead on a level (from *Chamarande* to *Bouray*); the engine was put, no longer only at the dead point, but at notches 10, 15, 20 of reverse gear (without injecting either steam or water). The areas of the diagrams (*figs.* 6, 7, 8 and 9) diminished of course, but remaining positive or motor.

2nd. Descending the incline from *Marolles* to *Brétigny*, diagrams (*figs.* 10 and 11) were equally taken off, at notches 25 and 30 of reverse gear. It is

only at the last notch that the area became negative or resisting (— 75 for the direct stroke. — 35 for the return stroke).

It is then, for a train run ahead only, between notches 25 and 30 of reverse gear that the change in the direction of the effort, is effected, as far as regards the steam.

According to the symmetry of the distribution, it ought to be admitted that the change should take place at the same notch of forward gear for the engine shunting its train, or, what comes to the same thing, drawing its tender foremost.

The points of the link which correspond to notches 30 are separated by a distance of 1.93 + 2.12 = 4.5 inches (table B); for notches 25 this distance is 3.27 inches. On the whole of this extent, the distribution can thus be done in the two directions; the direction of the effort of the steam on the pistons, is that of the movement previously existing.

These results must not doubtless be generalized; they apply to a particular case, but the conditions of which are realized more or less in the different valve-motions. These effects, which we hope soon to have time to study more completely, were quite unforeseen; perhaps they explain in part the relative want of power so often complained of with respect to counter-steam and which is the principal objection against it, on the part of many engineers.

It ought not to be lost sight of, at the same time, that these results, ob tained without injection of steam and of water, are not to be compared with those given by counter-steam under normal condition, that is to say with injection (219).

211. We cannot lay more stress on these considerations; but they lead us to bring out the importance of the mode of suspension of the link (164). This point describes an arc of a circle, the radius of which (that is to say the suspension rod) ought to be as great as possible; and on the other hand, everything else equal, the *disturbance* is so much the less and consequently the distribution so much the more regular in proportion as this point, or rather, the *finite* region of the link, which takes the stud in the course of one revolution of the axle, is nearer this arc with small versed sine.

In this double respect, it would be desirable that the point of suspension of the link were one of its extremities, which gives the rod its maximum length for a given position of the lifting shaft; and this ought to be, in the case of Stephenson's link with straight rods, the upper extremity in preference to the other, as the engine runs much more forwards than backwards.

This mode of suspension is however little adopted, because it only gives

sufficient length to the rod on condition of throwing the weigh-shaft below, which is not practicable in every type of engine.

If besides the suspension by one extremity is favourable to the gear to which that side corresponds, it is unfavourable for the other gear. Thus, with straight rods, the suspension by the bottom is little desirable, seeing that it throws the disturbance on the *forward gear*. It is the reverse for crossed rods; an argument of a certain value in favour of crossing, seeing that the suspension by the bottom has the advantage of being always easy, and allows a rod to be sufficiently long.

However, with the small admissions in use now, at least for high speed engines, the acting portion of the link approaches thus nearer to the middle than to the end and the suspension by the middle is on that account the best arrangement. With extreme suspensions while the extremity taken by the rod describes an arc of a circle *mn*, the other describes a curve $\alpha\beta\gamma\delta$ (Pl. VIII, *fig.* 27). With the suspension at the middle, the two extremities describe analogous curves *pqr*, *s*, *t*, *u* (*fig.* 28), and the distribution of the two gears are much less dissimilar : a consideration which has often led, in Germany for example, to the special application of this suspension to station engines, for which running backwards is of as much importance as forwards. This same mode seems as if it ought to be preferred in all cases in spite of the small length of rod to which it conduces. With well coordinated elements, it gives, altogether, very reduced amplitudes of disturbance, even for considerable introductions. But it is especially with *Gooch's* valve-motion that this diminution of disturbances is easy to realize.

§ IV. — Reversing screw.

212. *Disadvantages of the lever with segment and notches.* The lever, even with numerous notches allowing it to be fixed in a great number of positions, is always a defective instrument from the point of view of the use of expansion. It is in a continuous manner that the admission ought to vary. It is necessary, for the sake of solidity, to leave between the notches of the segment sufficient thickness of metal; so that often in passing from one notch to the next one, a point is jumped over, so to say, which would give a better distribution. Many drivers have made this remark. The disadvantage may be diminished, as on the Southern engines, by placing the lever, with two bolts, between two segments with alternate notches : But

it is far better to substitute a screw for the lever, allowing, on the one hand, the continuous variation of the admission, and on the other, this is the main point here, the reversing of the action of the steam without touching the regulator.

"In practice", says M. *Laurent*, locomotive engineer, on the subject of the six-wheeled engines exhibited in 1867 (II, 325, 394), this arrangement which allows the variation in the position of the lever by half a notch only, is amply sufficient, without any necessity of having recourse to the use of a reversing screw which theoretically may be a very satisfactory solution, but in practice, *presents serious drawbacks.*"

This latter opinion must certainly be shared, for the lever is far from being given up; it was found particularly, on a great number of engines exhibited at *Vienna*, in 1873.

What is certain, however, is that in the most powerful engines, the working of the slides under pressure by means of the screw is easy, sure, and without danger; it generally relieves the driver from all mistrust, and altogether the admission against the pistons is more rapidly obtained than by means of the lever, even when the latter answers completely.

Admitted on many lines, this point is contested on some others. This arises probably from the fact, that on the first, the drivers have become familiar with the screw while they are not so on the others. It is, as in so many other cases, a question of habit to adopt, and, what is more difficult, habit to be given up.

A service circular of the Mediterranean locomotive department (12 July 1867) pointed out, it is true, an anomaly, very rare however, observed with the reversing screw, only at starting. This operation, ordinarily so easy, meets in certain cases with an unusual resistance. The circular supposes that one of the slides was then nearly at the middle of its travel, covering the two ports, and that the smallness of the under pressure, and the sticking of the slide on the port-face on account of being still for a greater or less length of time, explained the reserved resistance; it recommends that no attempt should be made to overcome this resistance by an excessive effort on the screw wheel; to but close the regulator, to reopen it slightly, to work the screw, and only to open the regulator full when the starting has been effected.

The sole objection of any value (and more yet!) against the reversing screw applies to station engines. These passing at each instant from one gear to the other, the very frequent working of the handle, sometimes in one direction,

sometimes in the other, fatigues, and it is stated, *dazes* the drivers who prefer the lever to it. Thus on some lines, the latter has been substituted for the screw on station engines. But beyond this case, and, for drivers of irritable nerves, the advantages of the screw are manifest, especially for high speed engines; and almost all the drivers perfectly appreciate the convenience of this organ and the increase of personal security it brings them. With the lever it is often necessary, not only for reversing the action of the steam, but for the simple variations of admission in direct running, to commence by strangling greatly, if not to close the regulator. Hence too abrupt variations in the effort of traction, which strain the couplings much.

It has even happened on the Northern of Spain, that the drivers, meeting with too many difficulties in adapting the admission to the changes of gradient, leave the lever in an invariable position, and regulate the running by throttling the regulator. It was a question in this case of the heavy eight-wheeled coupled engines (II, 259) and with gun-metal slides with great friction. Filings were found on the port-faces; the alloy was badly prepared and its composition perhaps not in accordance with the specification.

The reversing screw, by the sole fact that it allows the valve-motion to be reversed under pressure, prevents at the same time the consequences which might result from a mishap, such as the fall of a bolt, rendering the closing of the regulator impossible.

213. *Combination of the lever and screw.* —It is sometimes desired to combine the two modes, lever and screw, because, it is said, at a low speed, the first is sufficient, and more prompt in effect, and because it allows of stopping immediately at a precise point, for example, under a chimney in the shed, etc. Hence, the combination adopted on the Belgian state railways. A half nut e, pressed by a spring r, is applied against the screw, and lifted, by pressing the handle when it is desired to act directly on the lever. The screw is inclined to the horizontal according to the inclination of the lever : a movement to which the articulation p of the support gives way (Pl. X, *fig.* 1.).

This combination of the lever with the screw was, moreover, the first way in which the latter was applied. It was, in effect, quite a natural way of managing the transmission. Thus, Kitson turned the screw with a square thread, on a core in the shape of a spindle, generated by the revolution of an arc of a circle having its centre at the point of rotation of the lever with bolt (*fig.* 2). The latter, pressed by a spring, is set into the

threads and remains in gear of itself, in all the positions of the lever, which can be set free at will, and act in the ordinary manner. Although the inclination of the screw, the pitch of which is constant, varies from one point to another, and although the bolt does not on that account take a full hold of the thread, this arrangement, simpler than that of the Belgian engines, was perhaps preferable. But the screw alone is in use on such a number of lines, and with such success, that it is difficult to uphold the necessity, or even the simple utility of the lever. The real utility of an organ is too often confounded with acquired habits, which its suppression interferes with.

In some engines, two screws with reverse threads were put on the shaft, the one working by a movable nut, the spindle ending on the lever of the weigh-shaft, the other travelling in a fixed nut of its support. The speed of the operation was thus increased without the necessity of exaggerating the inclination of the threads. But, now, the screw is always fixed.

The movement is a little slower, but the driver has no more need of going from his place, in order to follow the movement of translation of the screw and the handle.

The placing of the reversing screw may vary. There is sometimes set apart for it (Pl. X, *figs.* 3, 4 and 5) a double special support, *s*, *s*, bolted on to the foot-plate; oftener (*fig.* 6) this support, rudimentary in that case, is fixed on the fire-box, which has only the disadvantage of subjecting the transmission to the variations of length of the boiler.

The numerous examples of the application of the reversing screw contained in the atlas of vol. II are sufficient to give an idea of the diverse arrangements which can be given to this mechanism :

Pl. XXII. *Great Northern* engine, constructed at the *Creuzot* works (the vertical handle *m* works the screw *v*, *v*).

Pl. XXX et XXXII, *fig.* 1. High speed engine of the Northern of France (the screw is carried by a special frame).

Pl. XXXIII, *fig.* 1. High speed engine of the Western of France, and Pls. XXXV and XXXVII, *fig.* 1. High speed engine of the *Orleans* lines (the same arrangement as on the Northern of France.

Pl. LV. Eight-wheeled coupled engine *Kœchlin*. The support of the screw is riveted on to the side of the boiler; the driving spindle of the weigh-shaft is articulated directly on to the movable nut, and not, as in the preceding engines, on to the lower arm of a lever of the first order, representing the original reversing lever.

Pl. LVIII. Ten-wheeled coupled engine of the *Orleans* lines. The support riveted on to the boiler. The horizontal spindle drives the shaft by a ringing movement.

Pl. LXXIII. *Fairlie* engine of the *Oscarham* line. The movement of the handle, placed on the side of the boiler, is transmitted to the screw by conical gearing.

Pl. LXXXIII. *Rigi* engine. Vertical screw.

A graduated scale, and a runner in one piece with the nut indicate exactly the introduction of the steam in fractions of the stroke of the piston, for each of the gears, forward and backward : an indication which the notches of the lever, without taking their discontinuity into account, only give with the roughest approximation.

The reversing screw is the indispensable complement, far too much neglected for a long time, and even now, of the application of counter-steam to the *production of very prompt stoppages*.

For this case, the absence of a rapid and certain reversing mechanism was the sole obstacle to its use. The screw has filled up the hiatus. The disadvantages which we shall shortly analyze (217) only arise when running with counter-steam is long continued, that is to say, in the case of ordinary stoppages, and, naturally with more weight still, on the descent of long and very steep gradients.

214. *Unity of direction in the working of the lever or the screw, for straight or crossed rods.* One last observation. It is of considerable importance that this direction of the working of the lever or the screw should always be the same for the same direction of running. Otherwise, the driver would be exposed to hesitation, or to errors which might be productive of serious consequences in face of a necessity of the prompt reversing of the action of the steam. With *Stephenson's* link, and straight rods, the passage from *forward gear* to *backward gear* is effected by bringing the lever backwards (Pl. VIII, *fig.* 29); with the crossed rods, if the positions of the weigh-shaft, and of the counter-weight are the same (*fig.* 30), the lever on the contrary must be pushed over forwards. The unity of operation can be reestablished by transferring, in the second case, the shaft and the lever from 1 to 2 (*fig.* 30); but this modification might exert an injurious influence on the distribution; it is desirable, as much as possible, that the distribution shaft A should be placed on the side of concavity of Stephenson's link, and it is almost always easy to fulfil this second condition, while, at the same time satisfying the first.

§ V. — 2 nd case. **Longer continued running with counter-steam, and without reversing the rotation.**

215. *Distribution with counter-steam (or without reversing the rotation).* Let us return to the first period of counter-steam pushed as far as the reversing of the rotation, that which precedes this reversing; a very short period in the first case, but which in the two others, ought, on the contrary, to subsist alone, and may even be considerably prolonged in the third. The slides being put into backward gear, and so long as the direction of the rotation is not reversed, the distribution of the steam on the pistons, is effected under conditions the reverse of those of forward gear. Let us suppose, for example, that it is a question of a *Gooch's* link, and that the driver passes from full admission forwards to full admission backwards.

Let us take the piston at the commencement of its direct stroke, or from left to right; reversing the valve-motion has not changed the corresponding position of the slide; but instead of running at first in the same direction as the piston, it is going in the contrary direction, that is to say towards the left.

There is thus at first (Pl. VIII, fig. II) a very short introduction on the face A of the piston, which ceases as soon as the slide has run over the small admission lead. This small quantity of steam expands while the slide runs over the lap (or the sum of the laps, if there be an inside one), that is to say in the first case, until the slide is in the mean position, and in the second until it has passed by it, towards the left, by the length of the inside lap. At this moment, the communication is established between the left compartment of the cylinder and the atmosphere; and as the pressure of the steam, greatly expanded, which then fills it, is very inferior to the external pressure, the air, or rather the mixture of the hot gases from the smoke-box rushes, and the piston, continuing its motion, draws in more and more of this mixture. The face A is thus pressed, at first during an instant, by steam at a pressure, more or less below that of the boiler; afterwards by this steam which expands, and lastly by the gases at the atmospheric pressure.

What goes on at the same time on the face B? At the commencement of the stroke, the cylinder is filled with the mixture, at the atmospheric pressure, of gas and steam coming from the previous stroke. These gases, forced by the piston, escape into the atmosphere until the slide is in its mean position (or a little before if there is inside lap). From that moment,

and while the slide runs over the laps, these imprisoned gases are compressed by the piston.

Then, the port l' communicating with the valve-box, the steam comes on to the face B of the piston at full pressure, and is driven by it into the valve-box, and into the boiler. The resisting work on this face B comprehends then also three phases: forcing of the gases into the atmosphere, compression of the imprisoned gases, and running with counter-steam and driving back into the boiler.

The work applied on to each of the faces, during the direct stroke (from left to right), includes thus three distinct periods in running with counter-steam as in normal running, namely:

DIRECT STROKE OF THE PISTON.

	Running with motor steam	*Running with counter-steam.*
Face A	*a* admission of the steam.	*f'* admission.
	b expansion.	*e'* expansion.
	c anticipated exhaust (piston running).	*d'* communication with the atmosphere (drawing in the gases).
Face B	*d* exhaust (piston forcing).	*c'* exhaust (piston forcing).
	e compression of the steam confined.	*b'* compression.
	f counter-steam (before admission).	*a'* counter-steam, and driving into the valve-box and the boiler.

The same letters designate the phases which correspond in the two states of the valve-motion.

It is clear that the various graphic outlines (157, 158, 161, 163) apply to this reverse running as to direct running. If, for example, full admission backwards is passed to from full admission forwards, there is nothing to do, α and α' being the two angles at which the eccentrics are keyed on, but to replace the angular advance α, by the advance $180^\circ - \alpha'$ this case entering into that of the independent rods (157, 158).

The following are, according to observations made by M. *Guébhard* on an Eastern of France engine with eight wheels coupled, stroke 2. 16 feet, the lengths of the twelve events at the fifth notch.

Direct running.....	ins *a*, 10,67	ins *b*, 10,83	ins *c*, 4,49	ins *d*, 19,68	ins *e*, 6,02	ins *f*, 0,28
Reverse running.....	ins *f'* 0,51	ins *e'* 8,90	ins *d'* 16,57	ins *c'* 4,65	ins *b'* 10,83	ins *a'* 10,51

216. The reversing of the rotation, that is to say slipping, ought, as we have stated (203), to be absolutely excluded. The suppression of sliding constitutes, with the rapidity of the action, the two great advantages of this special brake. Slipping is avoided by placing the slide, no longer, as in the preceding case, at the end of the travel for backward gear, but farther from that limit the less favourable the state of the rails. By sacrificing thus a portion of the power of the instrument, of the *pushing* force, the driver must begin the reversing a little sooner, and, at need, with the assistance of the ordinary brakes, which he could often do without, and to manage so that the whole *vis viva* of the brake may be extinguished, without the driving wheels reversing at the moment when he reaches the station.

Accessory, and relatively short in the case of abrupt stoppage, the first period (203) is continued in the latter, during the whole duration of the retarded movement, so that disadvantages which may be neglected in the one acquire already in the other, by their continuation and their accumulation, such weight that the application of the process would become impracticable.

217. *Disadvantages of this running.* We see that, in the situation in question, the part of the piston consists essentially in drawing the gases from the smoke-box and forcing them afterwards pell-mell with the steam coming from the boiler, into the valve-box, then into the boiler itself.

These gases are, at a variable temperature, in the smoke-box rarely below 570°, and at times very much higher, up to 930°. From the moment when the distribution is reversed, this temperature lowers rapidly, it is true, the steam sent back into the boiler instead of being thrown out in the blast, having no longer any action on the draught. But the gases drawn in bring with them solid particles: ashes, bits of fuel, cinders which, introduced into the cylinders, scratch them as well as the pistons.

Compressed and forced into the boiler, these gases raise the pressure therein, which the very insufficient rise of the safety valves (74) would allow to mount up rapidly to several atmospheres above the regulation figure.

These gases prevent the injector from acting, because the feedwater put, even at a low temperature, in presence of a mixture too hot and charged with gases not liquefiable, cannot effect the condensation, which is the principle of the action of the apparatus. But this is not all.

The cylinders, the pistons and the slides are subjected to a temperature very much more elevated than that which would result, from forcing in, at

the pressure of the boiler, the gases more or less hot drawn in from the smoke-box.

At the moment when the 3rd. period commences (a') on the face B (215), the right hand compartment of the cylinder is filled with steam and gas at a pressure a little greater than that of the atmosphere, but much inferior to that of the boiler, and of the valve-box. There is thus an abrupt compression of the first, and consequently an abrupt disengagement of heat; hence a considerable elevation of the temperature of the mixture, and of the bodies in contact with it: the fatty matters burn, the packings of the *stuffing-boxes* are carbonized, the piston rods heat to the point of getting blue; the rubbing surfaces gripe and wear, the more rapidly in proportion as the presence of the solid particles brought over by the gases comes in to aggravate the whole.

It is this local heating which is the most injurious, and it would soon take such proportions, as to seriously compromise the whole of the machinery.

Under penalty of losing a great deal of time, all the means applied to produce the stoppage at stations should have power enough to render the distance run as small as possible. It is not sufficient, however, that the disadvantages indicated do not show themselves; when the stations are very close together, especially, the effects accumulate, the pistons and the cylinders not having the time to lose, during the interval, their excess of temperature.

§ VI. — 3rd. Case. **Moderation of velocity down inclines**

218. On the descent of long and very steep gradients, it is necessary, in order to maintain (and at need to bring back) the velocity to the figure fixed by prudence, to balance in consequence a part of the action of gravity. The retarding force that the engine can supply is limited then, and more necessarily than in the case of ordinary stoppages, on account of the duration of the action, through the condition of avoiding the reversing of the rotation (203).

Abstraction made of the effects of this slipping (which would determine an immediate lowering of the coefficient of friction), the counter-steam, *with the reversing of the rotation*, would give, at the *same notch of admission*, a *holding back* effort on the pistons, equal to the effort of *traction*.

An engine capable of drawing a load up a gradient, and at a given velocity, could then maintain, on the descent, the same uniform velocity of the

same train; and that *a fortiori*, seeing that the effort of *traction* is the sum of the efforts of gravity, and the resistances proper of the train, while the *holding back* effort is only their difference. But the reversing of the rotation being excluded, the distribution of the work on the two faces of the piston, and consequently the mean *useful* effect, are no longer the same, for the same degrees of admission, on the ascent, and on the descent; this effort is less in the second case, and it may even, for a reverse admission more or less extended according to the type of the valve-motion, become *negative*, that is to say to still give on the pistons, and even on the coupling bar, an effort of *traction* (206, 210).

219. *Means of escaping from the disadvantages pointed out.* — We shall shortly return to this point : the power of the counter-steam (224). But let us first examine the means applied in order to get rid of the disadvantages pointed out (217), and the gravity of which is such that running with counter-steam, especially prolonged as it ought to be on long inclines, was only possible with an extremely limited admission (*), consequently, with a result almost insignificant.

First the palliatives. 1st. As regards the danger of an excess of pressure in the boiler, it must be seen to, that the driver, on coming to a heavy incline, loosens the springs of the safety valves.

2nd. The disadvantages inherent to the impurity, and the high initial temperature of the gases drawn in, may be avoided by putting the exhaust in direct communication with the atmosphere, and not by the intermedium of the smoke-box, so that the pistons draw in pure air and at the external temperature.

We have already cited (II, 437) an example of the application of this principle, but combined with another important arrangement; the cylinders are completely isolated from the boiler, so that the air drawn in is forced, not into the latter, but into a special capacity, as in M. *Debergue's* brake, or into the atmosphere, by an opening which the driver throttles more or less.

It is thus, no longer counter-steam, but a system apart, susceptible perhaps of more frequent applications than those which it has received, on condition at the same time of completing it, as M. *Riggenbach* has done at

(*) *Des locomotives très puissantes et à petite vitesse*, by M. *Couche*. *Annales des mines*, 5th series, vol. VI, 1854, p. 395.

the *Rigi* (II, 437) by the suppression of the third disadvantage, the *heating* of the cylinders.

This air brake excludes the possibility of sending back into the boiler, under the form of heat, as with steam, a part of the *vis viva* of the train or of the work of gravity on inclines. But this consequence of *counter-steam* is little more than theoretical. It is very rare that the driver has occasion to take advantage of this faculty, in order to bring up a pressure fallen too low. Not only is the heat in question lost, but there is even, in opposition to the principle indicated farther on (224), although perhaps not necessarily, a notable expenditure of fuel.

Instead of having recourse to the external atmosphere, where the pistons draw in pure air, it is true, but not liquefiable, it is far preferable (and it is in this that consists the improvement made in counter-steam as it is applied) to create in the exhaust an atmosphere free from gas, formed of steam taken from the boiler. The small tube which brings it branches into two, and opens, under the slides, into the base of the exhaust pipe from each of the cylinders. Thus are avoided : 1st., the high initial temperature of the gases drawn in, the expanded steam having a pressure, and a temperature little superior to 1 atmosphere and 212°; 2nd., the aspiration of solid matters; 3rd., the action proper of the hot gases on the frictions; steam on the contrary lubricating the surfaces; 4th., the forcing into the boiler, of gas which rapidly raises the pressure therein, and opposes the action of the injector.

There remains the *local* elevation of the temperature. This is remedied by injecting through the same tube, and in proportion regulated at will, water, which by its evaporation, absorbs the excess of heat due to the compression, and limits the temperature.

The steam on one hand, and the water on the other, have thus each up to a certain point a special function. The one creates the artificial atmosphere in the exhaust, the other combats the elevation of temperature, which is produced especially at the moment of the reverse admission, (217). The steam can only fulfil the first function. The water, by evaporating, may fulfil both at the same time.

Figs. 3, 4, 5 (Pl. X), represent the apparatus applied on the Mediterranean system to the engines with six coupled wheels. The water and the steam are brought in by two separate tubes, A, B, the one 1.2 and the other 1.6 inches in diameter, to a common box M, and leave it by the same tube C ending, as we have seen, by a bifurcation, in the two exhaust pipes.

The proportion of the two elements is regulated by means of two slides t, t' with screwed rods worked by the cranks, m, m'.

In the first application of the injection, made in 1865 on the Northern of Spain, and the description of which (*) served as guide to the *Mediterranean*, where it was first applied in France, the proportion of the two elements was invariable. Although less simple, the *Mediterranean* arrangement is preferable without doubt. It allows of running, either with the steam alone, which is sufficient, on slight inclines where the local heating is small, or with water alone which is sufficient, excepting in some particular circumstances (221).

220. *Conditions of the application of counter-steam. Examples.* An instruction (No. 104, 12 th. June 1867) of the Mediterranean locomotive department has laid down various practical rules for the use of counter-steam. We reproduce the most important :

"ART. 1. Before starting, in order to undertake any movement, the driver ought :

"1. Open the two side cocks on the boiler which open the passage of the water and of the steam, from the boiler to the slide injection box;

"2. To put his valve-motion at the dead point, then open his regulator full.

"ART. 2. He puts his engine in motion by regulating the admission of the steam by the valve-motion alone, without touching the regulator.

"The regulator, open before starting, ought to remain open all the time the engine is kept in motion.

"ART. 3. When use is made of counter-steam, the volume of steam injected into the exhaust pipe should always exceed the volume drawn in by the piston, in order to prevent air and the gases produced by combustion being drawn in; it ought not to exceed it much, as this would cause a useless expenditure to the boiler.

"In order to obtain the suitable amount of injection, the driver regulates the position of the steam injection slide in such a manner, that there may be constantly perceived a slight cloud of steam coming out in a continuous jet, through the chimney.

"The insufficiency of the volume of steam injected is manifested by the following :

"1. No steam escapes from the chimney, or it escapes by intermittent jets;

"2. The pressure rises in the boiler;

"3. The *Giffard* injector stops, if it was acting; it does not work if it had stopped.

"The excess of the volume of steam is manifested by the exaggerated importance of the jet passing out of the chimney.

"ART. 4. The volume of water injected into the exhaust pipe ought to be sufficient to prevent, by evaporation, the increase of the pressure and of the heat of the cylinders. This volume ought not to be carried beyond what is necessary in order to obtain the effect pointed out above, which would cause a useless expenditure for the boiler, a diminution of the resisting work on account of the condensation in the cylinder of the com-

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(*) *Rapport sur les inconvénients des freins ordinaires, et ceux sur l'emploi régulier de la contre-vapeur*, by M. *Ricour*. *Annales des mines*, 6th series, vol. V, 1866, p. 14.

pressed steam, and lastly, the useless and sometimes dangerous presence of an excess of water in the cylinders.

"In order to obtain the suitable amount of injection, the driver ought to regulate the position of the injection slide in such a manner that a small excess of water may escape through the chimney and produce a spray like that which escapes from an engine which is slightly priming.

"The insufficiency of the volume of water injected is manifested by the following:

"1. No water escapes through the chimney;

"2. The manometer indicates an increase of pressure in the boiler;

"3. If the insufficiency of the water is continued during some instants only, the pressure rises considerably, the packings of the slide and of the pistons heat and burn rapidly, the slides gripe on the faces, in fine, the old disadvantages of running with counter-steam occur again.

"The excess of the injection of water is manifested by an abundant shower out of the chimney.

"ART. 5. When, in reverse running, the reaction of the steam is superior to the adhesion of the driving and coupled wheels, the engine slips backwards, the parts of the valve-motion are then animated with a great speed, and the reactions which result on the link are so considerable that it may be very difficult, even with the screw, to reduce the introduction.

"Consequently, as soon as the engine slips, the driver ought at first, and without any hesitation to shut his regulator, the slipping stops immediately; then he opens the regulator again and regulates anew the admission for the reverse gear, keeping below the admission wich produced the slipping.

"ART. 6. If the *Giffard* injector stops, or if it will not work, the driver increases the injection of steam and of water into the cylinders, and brings his valve-motion close to the dead point, but keeping in the reverse gear, and taking care to have the brakes tightened in order to prevent the acceleration of the velocity of the train; if these means are insufficient, he opens the blow-off cock, in order to clear out the fixed gases introduced into the boiler, which stop the action of the injector. By one of these means, the *Giffard* injector can always be made to work if it is in good order.

If during the stoppage of the *Giffard* the water in the boiler is too low, the driver stops his train. But in order to avoid the use of this extreme measure, he ought always to keep the level of the water in the boiler at a high level.

"ART. 7. It is formally interdicted, when use of counter-steam has to be made in order to moderate the velocity of trains down inclines, to lubricate the slides or the cylinders before starting or during the journey.

"Greasy matters driven into the boiler would make the engine prime and would cause an uprise of the water which would completely falsify the indications of the water level; the fire-box would thus be exposed to burning.

"ART. 8. The driver ought, during running with counter-steam, to pay most particular attention to the manometer; when the counter-steam is employed in order to moderate the velocity of trains, on a distance of more than half a mile, the valves are unscrewed to the extent of 15 lbs. to the square inch, below their normal pressure, in order to warn the driver in time and to limit that increase.

. . . . . .

ART. 10. When the length of a stoppage is not to exceed 10 minutes, it is sufficient, as in an orninary stoppage, to close the injection slides for water and steam.

" When a stoppage is to be longer than 10 minutes, and during the stay of an engine in the depôt, the cocks of communication of the water and the steam between the boiler and the injection box, ought to be constantly closed as well as the steam and water injection slides.

"ART. 12. In order to moderate the velocity of trains down steep inclines, the driver puts his valve-motion over beyond the dead point, and stops it at the first division of the reverse gear.

" He opens the steam injection slide, then the water injection slide.

" He regulates the reverse admission of the steam into the cylinders in proportion to the resistance to be produced in order to moderate the velocity of the train, and brings it, if necessary, nearly to the admission which would produce slipping.

. . . . . .

"ART. 17. When two engines are at the head of a train, the driver of the front one regulates first the velocity by employing counter-steam up to the limit of admission which would produce reverse slipping; at the same time the second driver, warned by the suppression of the blast in the first engine, puts his valve-motion over to the firs division of reverse gear.

" If the counter-steam of the first engine, at its limit, is insufficient, the front driver gives two long whistles; at this signal the second driver puts his valve-motion over to the limit of the reverse gear, the first then regulates the velocity of the train by varying suitably his reverse admission.

. . . . . .

" ART. 20. When one only of the engines is provided with counter-steam apparatus, the driver of that engine places it always in front, and regulates the running. The second driver makes use of the counter-steam, by means of the old reversing lever, but only in the case of a signal to stop or of apparent danger.

. . . . . .

"ART. 23. If there is, beside the engine or engines in front, an engine behind: in ordinary cases the driver never makes use of counter-steam beyond the first division of the distribution.

" When the train comes to an incline above one in 250, the driver behind places, of his own accord, his distribution at the first division of reverse gear."

This apparently unimportant use, of the hinder engine (which ought besides to be brought as much as possible to the front in the descent of long and heavy inclines, results of course from the necessity of avoiding the breakages of couplings. It is only in the presence of danger, and when the continued whistles of the front driver require him to bring into immediate operation every means of stopping, that the driver behind, leaving aside then all ordinary considerations, goes beyond, and even as far as the reverse admission to the full travel of the slides (art. 24).

"ART. 27. Notwithstanding the new facilities brought in by counter-steam, the screwing up of the brakes by the guards, in case of a stoppage to be produced has been continued without modification.

"At first, the regulation working of the brakes is obligatory on all. Further, it is always useful. In effect, the certainty of the stoppages will be much increased by the use of the two means: tightening up the brakes of the train, and counter-steam, and by keeping, as we have done for *last operation in case of urgency* the counter-steam, the almost instantaneous effect of which is always at the disposal of the driver.

"The working of the carriage brakes is besides indispensable for abrupt stoppages of trains, and in the cases in which counter-steam fails through want of pressure or damage to the boiler, and if the habitual use of these brakes were not maintained, they would fail in cases of urgency.

"The drivers ought then, in case of urgency, to allow the guards brakes to act first, and only to employ counter-steam in the case of insufficiency of these brakes."

But already for a long time, experience on this line has led to make a much greater use of counter-steam as one of the means of stopping. It is employed regularly in the service, even for simple slackenings and ordinary stoppages at stations; and the brake, formerly the most worked, that of the tender, has only at the present time a secondary part, to the great advantage of its tires and brake blocks.

In general, drivers hardly ever avoid having recourse to counter-steam, but when they have just lubricated the slides, as the oil would then be driven into the boiler.

When it freezes, some precautions have to be taken to avoid the freezing of the water in the injection box and tubes. An instruction (No. 119) defines them as follows:

"1. *During running.* While running, the steam and water-cocks ought to be constantly open; this communication is sufficient, in general, to prevent the cooling of the steam and water tubes, and of the injection-box. However, when the temperature of the air is very low, the condensed water, either in these apparatus, or even in the angles of the injection-tubes near the breeches pipe of the exhaust, might get frozen; in order to avoid this accident, the driver ought to ascertain the temperature of the tubes, and of the injection-box by feeling them with his hand, and when that temperature perceptibly lowers, he ought to open for a few instants the water injection-slide in order to renew the water; afterwards, after having closed the slide, he opens for some instants the steam injection-slide, in order to drive out the water which might have remained in the injection-tube. This operation ought to be renewed as often as necessary in order to maintain the apparatus at a gentle heat.

"2. *During standing.* On arriving at a stopping point or standing, the driver ought to open the steam injection-slide, in order to throw into the chimney the water which might have remained in the injection-tube.

"When the length of time standing is longer than 10', during the stay of the engines in the shed, the water and steam entrance-cocks ought to be closed, as well as the injection-slides, while on the contrary, the blow-off cock of the water tube is open, in order to get rid of the water or the steam which might get in through leaks in the cocks."

Eastern of France. An instruction of the locomotive department of the Eastern of France states (art. 299) :

"In general, for every change of gradient which necessitates a modification in the resistance which the steam-brake opposes to the push of the train, the drivers ought only to occupy themselves with working the reversing lever (or screw) and not the regulator, in such a way as to maintain a uniform velocity. Beyond, they ought, unless in an urgent case, to avoid any abrupt working of the lever, as for example the passage from a notch in forward gear to a notch of backward gear from the dead point. This change ought to be made by degrees, in order to avoid the production of violent shocks."

Northern of France. On the Northern of France according to M. *Lechatelier* (*), the injection of steam alone has been applied to the engines which run on inclines of one in 100 at the most; the injection of water is reserved for the engines working on the sections, few in number, where the inclination reaches one in 100.

Greater and more prolonged reverse admission develops in effect (217) a more considerable local heating. But in reality, the use of counter-steam is very restricted at the present time on the Northern of France. It is regarded as an instrument applicable chiefly to the descent of inclines both long and steep; beyond this case, ordinary brakes seem simpler to them, and better suited to the conditions of working, a general opinion, which may be warranted by this fact, that ordinary hand-brakes are more frequent on these lines than any others.

Orleans lines, injection of water only. On the *Orleans* lines, the admission of steam and water together, copied from the Northern of Spain, gave place afterwards, on the steep gradient engines, to an injection of water alone, which reduced the apparatus to the maximum simplicity, with a single cock. That this cock may suffice in general, that is not doubtful; it is called *water-cock* because it takes from below the level of the water; but this water taken at about 324° in the boiler, is, in the cylinders, only very moist steam, which realizes at the same time the inoffensive exhaust atmosphere, and the absorption of the heat of compression. Experience proves at the

(*) *Mémoire sur la marche à contre-vapeur. Paris, Paul Dupont,* 1869, p. 43.

same time that the injection of water gives very much milder frictions than the combined injection, into which the steam enters too often in an exaggerated proportion. After prolonged reverse running, with injection of steam, the difficulty of working the lever and even of the screw often reappears on this account. It is not the same with water alone, and many engineers go so far as to assert that it renders the screw useless; but this is only looking at one side of the question (212).

As, with the two independent admissions, nothing prevents the driver from giving only water if he thinks fit, it is preferable to keep this arrangement, all the more that it is good, in most cases, to commence by injecting a little steam.

221. *Maintaining the special steam-cock. Its grounds.* — 1st. In the engines in which the lever has not been replaced by the screw, and the regulator of which ought, on that account, to be closed before the valve-motion is reversed, the drawing in and forcing of the gases ought to be prevented by the previous opening of the injection. In case of delay in this operation, and if the regulator is not opened again very promptly, the boiler soon receives a quantity of air sufficient to check the working of the *Giffard's* injector. The injection of water makes no change in this position, while the injection of steam rapidly clears out the boiler from the imprisoned air. In addition, the driver has, without even loosening the valves, simple means of expelling that air, the whistle and the blower; but it is more convenient still to do everything at once by the injection of steam.

2nd. There is besides another motive for retaining it. In ordinary weather, the normal velocity is kept up very nearly of itself, without effort of traction, or thrust of the steam on the pistons : for passenger trains, on gradients of one in 100, for goods trains on gradients of one in 200 ; and although the driver takes care, in closing the regulator, to put over the distribution at the end of the travel in forward gear, in order to reduce the period of compression of the air drawn in the smoke-box (148-3rd), the latter still heats and dirties the cylinders. By opening the regulator from time to time to let in a thread of steam, the driver reduces this effect; but it is far better to leave the regulator closed, and create an inoffensive atmosphere by an injection of steam into the exhaust. This is besides a means of widening the limit of application of direct running with closed regulator. It is sufficient to place the valve-motion at an intermediate notch in order to increase, without disadvantage, the efforts of compression, and consequently the resistance opposed by the engine.

The water-cock ought to have very great sensibility; only a slight conicity must be given to it in order that a notable displacement may correspond to a very small variation of the annular section of discharge. The steam-cock, having no need of this sensibility, can have a much greater amount of conicity.

❀❀❀. Counter-steam with an injection is an energetic brake, at least at low speed (227), and which has only the disadvantage of requiring, when its use is long continued, as on the descent of steep gradients, a notable expenditure of fuel (224), and continued attention on the part of the driver. He ought constantly to have his eye on the manometer; on the temperature of the cylinders; on the chimney, which ought continually to let out a little steam, the sign of the existence in excess of the inoffensive atmosphere, and on the slipping. This explains, without justifying it, the little liking that the great numbers of drivers have for this brake. If they made use of it regularly, they would accustom themselves to the duties which it involves, and their opposition which is more or less assumed would disappear. Even with large admissions everything goes on, in the hands of an attentive driver, in a satisfactory manner. M. *Marie* cites (*) the descent of a train of from 700 to 800 tons down the *St.-Étienne* incline. With an admission of 70 per cent, an injection of 24 lbs. of steam and 35 lbs. of water, the packings not only kept well also, but much better than on the descent in direct running, regulator closed.

Let us remark in passing, that with the view of running with counter-steam or to carefully lubricate the lower guides of the piston rods, a secondary matter in direct running, these guides having then no effort to support.

It is often objected that the driver, notwithstanding all his attention, cannot avoid continual and abrupt variations of the pressure in the boiler, variations which rapidly derange the manometer, the needle of which is incessantly oscillating, and strain the boiler; but the oscillations are only very marked when the boiler contains air, that is to say when the injection has not been correctly applied. With the counter-steam obligatory, it is added, that the driver's task would be much more hard on the descent of heavy inclines than on the ascent.

This statement is a little exaggerated.

(*) Letter of the 11th february 1867 to M. Lechatelier. *Mémoire sur la marche à contre-vapeur. Paul Dupont. Paris*, 1869, p. 95.

We have seen (220), that on some systems, the Eastern of France, the *Mediterranean* among others, the use of counter-steam is prescribed to the drivers, not only to moderate the velocity down inclines, but also for the stoppages at the stations. On the Eastern of France, indeed (art. 29 of the regulations) the drivers ought only in general to have recourse to the tender-brake for determining the complete stoppage of the train already greatly slackened by counter-steam.

The tender-brake is kept as eventual addition, for the case where the guards of the train might pay no attention to the driver's signals (art. 294), and the latter ought in no case, going down inclines, to apply to the brakesman before having placed the valve-motion at the sixth notch of backward gear :

Southern of Austria lines. — In reality however, counter-steam is very unequally applied, and much less than is often believed, even on steep inclines. On the stiffest part of the continental system, for example, that is to say on the Southern of Austria lines, which include the *Brenner*, the *Karst*, the *Semmering*, the *Villach* to *Franzenfest*, ordinary brakes still constitute the normal means of moderating the velocity on the inclines; the driver only comes in with counter-steam on account of lazy working or insufficient action of the brakes. Counter-steam is in a word, only a supplementary brake; a distress brake; an arrangement which has the advantage of keeping the attention of the guards alive to the feeling of their responsibility, although in fact, these men may be somewhat too sure by the confidence they feel in such an auxiliary as counter-steam.

As to the regular stoppages at stations, the drivers are free to use it or not, and it is the latter part they almost always take.

M. *Gottschalk* has been good enough to communicate to me the following observations on the facts which I had recorded; they emanate from an engineer too well placed for appreciating the requirements of safety in running down steep inclines, for me not to take the opportunity of making them known.

"On account of the necessities of service and of the troublesome tendency, according to me, of always increasing the velocities of passenger trains, our passenger trains, even on the descent of the *Semring* and of the *Brenner*, run too rapidly for it to be advantageous, I will say in certain cases, and particularly for the expresses, even prudent to make use of counter-steam.

"At these velocities, and particularly in a mountainous country, the wheels of the engines have a tendency, under the influence of the counter-steam, to slip in the direction opposed to the running; in this case, and I have myself had occasion to experience it more than once, the engine is as it were lifted up, and no longer opposes resistance to the descent of the train, which then takes considerable velocities.

If then the breaks are called for, the staff of guards belonging to another department and having too much confidence in the steam-brake, do not pay sufficient attention to the orders of the whistle, or are not at their posts, or indeed are asleep. There remains no other means of stoppage for the engine staff than the tender brake, altogether insufficient; and it has happened in former times that trains abandoned thus to themselves, the brakes put on too late, descended with frightful velocities.

"I can cite the case of a train which ran down, without accident, it is true, at a velocity of 62 miles an hour.

"It is this which was the cause of the measure taken four or five years ago and maintained hitherto, of only considering running with counter-steam *as a supplementary means*, put at the disposal of the driver in order to regulate the velocity, and at need to produce a rapid stoppage of the train in front of an obstacle signalled or perceived on the line. Our goods trains running relatively much slower than the passenger ones, we could very well make use in this case of counter-steam for the descent, and, in fact, our drivers, are now perfectly up to the working of the steam and water-cocks, and employ much oftener this means of regulating the running with goods trains than with passenger trains. At the same time as a measure of safety, we have thought well to extend to trains of all sorts the rule followed for passenger trains, in only rendering running with counter-steam obligatory *in the case of too great velocity or of an obstacle* on the line.

"I should desire nothing better than to save the tires, of which we have made this winter (74–75) a considerable consumption, by rendering obligatory, in all circumstances, running with counter-steam; but the remembrance of the past makes me fear for the safety, and I shall wait in order to apply this measure until the improvement of continuous brakes, to be worked from the engine, renders us altogether independent of brakesmen."

223. It is a long way from that to what is supposed and what is repeated every day, touching the part of counter-steam in the descent of mountain lines.

M. *Gottschalk's* arguments are certainly of great value.

If the use of counter-steam were rendered compulsory, the brakesmen would rely still more on it; they would consider themselves freed from responsibility, and their negligence would be more frequent.

It is however much to be regretted that counter-steam should be reserved for the extreme cases, in which its efficacy is small (227), of a train having acquired too great a speed, instead of employing it to prevent this excess of velocity from being produced.

Drivers are always free, it is true, to make use of it, but many of them still hold strong prejudices against it. As long as they can dispense with it, they will rarely apply it, and only have recourse thereto in the face of danger, which might at times have been prevented by acting sooner.

Some cases of the valves sticking on the port-faces, often serve as a pre-

text for their opposition; but these accidents occur also without counter-steam, and to which they cannot be imputed.

Upper Italy. Its use has been orderer on this system of lines, which includes the heavy gradients of Bardonnecchia, of Giari and of Pracchia.

In the first engines, the two steam and water cocks ended, as on the *Mediterranee*, in a *mixing* box. In the others, the two cocks exist also, but the box is suppressed. The two tubes *t*, *t'* (Pl. X, *fig.* 7) are in one which branches off into two, in order to carry the mixture of steam and water made in the tube itself under the two slides.

The steam-cock is in this case only an accessory, kept for drivers not acquainted with the use of water alone.

We take from the special instructions in use on that system of lines (*) the principal rules prescribed for the use of counter-steam.

"1. *Stoppages in front of an obstacle.* 1. "To open the water injection; 2. to reverse the valve-motion right over. This is easy and without danger even with the lever, and the regulator open, as soon as the injection of water takes place.

"2. *Ordinary stoppages at stations.* 1. To open the water injection cock; 2. to reverse by degrees, and only at the point indicated for slackening the train; 3. before reaching the platform, to close the water injection and to replace it by an injection of steam, so as to prevent or at least reduce water going off by the chimney;

"2. This, without prejudice to the action of the ordinary brakes which the driver calls for at the beginning, if he thinks proper, and which, in all cases, serve specially for bringing the train completely up, after being slackened by the counter-steam;

"3. After the stoppage the regulator and the steam-cock are closed, the valve-motion put at the dead point, and the blow-off cocks opened.

"3. *Descent of inclines.* "On inclines such that gravity alone maintains the normal speed: to send a little steam into the exhaust, to close the regulator, and put the valve-motion full in *forward* gear. The thread of steam drawn in by the piston lubricates the piston, and dispenses with oiling.

"If the velocity increases, it is sufficient in order to check it, to put the valve-motion always in forward gear, at 40 or 50 per cent of admission, which increases the compression of the steam drawn in, and creates a greater resistsnce.

"2. When the reversing of the valve-motion is necessary (and especially on the descent from the middle of the great tunnel to *Modane*, from *Bardonnecchia* to *Bussolano*, from *Bussalla* to *Ponte Decimo*, from *Pracchia* to *Casalecchio* and to *Pistoja*), the driver ought not to oil the slides or the cylinders; the greasy matters driven into the boiler, would produce, without counting the priming through the chimney, a swelling up of the water which would put the gauge glass wrong and would expose the fire-box to be burnt."

(*) *Istruzione per l'uso del contro-vapore, e per la condotte en trani con due o più locomotive,* 1873.

The use of counter-steam is obligatory in the three cases which we have distinguished (202), and in the last, the ordinary brakes ought only to intervene, if the first is insufficient. This is then the reverse of what is in force on the South Austrian.

"It is generally sufficient to put the reverse admission at 50 or 60 per cent. of the stroke of the piston.

"Every driver who, not having been able to command his train, and has run past a stopping-station, is punished by a fine, and by being put in a lower grade in case of a repetition."

Safety lines. Measures are besides taken at the most dangerous stations in order to avert the consequences of this fact. From the main line branches out a *safety* piece of line, the points of which, always open to that line run the train up a very steep contrary incline, on which it loses its velocity (*).

"When the pressure in the boiler rises, the driver makes use of known means: feeding, exhaust full open, more abundant injection of water, etc.

"When the injector refuses to work, that arises from the presence of air in the boiler, from one of the following causes: 1st. reversing the valve-motion before opening the injection cock; 2nd. closing the regulator before putting the valve-motion over to the end of the travel; 3rd. injection of air to prevent air getting into the exhaust.

"This air can be expelled by opening the blower and the whistle.

"*Trains drawn by more than one engine.* 1st. Descent of gradients with several engines at the head of the train. The front driver puts himself into backward gear right over, that is to say nearly at the point at which the rotation would be reversed. The second driver, warned by the stoppage of the blast, and without any other signal, reverses his valve-motion by degrees until the velocity is brought down to the desired point. It is only in the case of insufficiency of the engines that the driver of the first one whistles for the brakes.

2nd. Descent with an engine behind:

"In general, the engine which has pushed a train going up an incline, ought, if accompanying the train, to be brought on to the front for a following descent.

"Engines behind employed as auxiliaries are not coupled on; when the train reaches the top of the incline, the front driver gives two long whistles to the other who, on this signal, immediately reverses his steam.

"In the great Mount Cenis tunnel, the trains have in both directions an engine behind, which cannot leave them until one of the two pieces of level is reached, the one at the culminating point, towards the middle of the tunnel, the other, near *Bardonnecchia*, on the first half mile."

(*) These lines are established at *Meana*, *Chiomonte*, *Giovi*, *Pittecio*, and *Moleno del Pallone*.

Consumption and power of counter-steam by reversing the valve-motion.

224. *Consumption.* In direct running, the engine transforms heat into work; the latter, less the portion absorbed on ascending gradients by gravity, is afterwards transformed almost entirely into heat by the friction.

During stoppages and on the descent of inclines, in reverse running *at a notch high enough* (206-210), the engine transforms the *vis viva* of the train, or a portion of the motor work of gravity into heat, a portion of which is sent back into the boiler, and of which the other is carried off chiefly by the excess of steam which has to be lost in order to give the driver the certainty that the access to the exhaust is quite closed against the gases from the smoke-box.

The pressure in the boiler might thus be maintained, without expenditure of fuel, if the heat that is returned to it compensated that which is taken from it by that discharge of steam, and radiation.

It was once tried, on the *Brenner*, to realize this sending into the boiler, the heat arising from the work of gravity destroyed. The train having reached the summit, the fire was thrown down; but it was soon necessary to give up the spontaneous raising of the pressure, on account of the numerous leaks at the ferrules, determined by the passage of the cold air through the tubes.

In fact, on long inclines the consumption of fuel caused by the counter-steam, is considerable:

"In reality," says Mr. *Lechatelier* (*) "in the actual practice of counter-steam, the fire plays a great part in keeping up the pressure in the boiler; and when the valves are seen to blow off, it is to its greater or less activity that effect should be attributed. It is then necessary to admit a certain supplementary consumption of fuel for the run with counter-steam down somewhat long inclines. I have collected two examples, one of 1s. 4d., the other of 2s. 3d., for the cost per mile over the normal cost on the descent under the action of brakes.

On the gradients of one in 67 in the Pyrenees (Northern of Spain) according to the observations made by M. *Bourson* in 1869, the consumption per mile of the 8 wheels coupled engines running in counter-steam, was on the average 10 lbs. When the counter-steam was not in action, the train being retained

(*) *Mémoire sur la marche à contre-vapeur*, page 101.

by the brakes, the engine consumed, for the keeping up of the fire, 1.76 lbs. The actual consumption of the counter-steam amounted then to 4.84 lbs. These figures, certainly high, are without any doubt susceptible of reduction; and even were they not so, the advantage of reducing, if not of suppressing, the destructive action of ordinary brakes, too often jammed up tight and insufficient, would not be too dearly bought at this price.

225. *Magnitude of the retarding force.* This increase of consumption must however seem the more regrettable, because the restraining effort which the engine can apply without the reversing of the rotation, is often very inferior to its tractive effort for the same notch (224) (if indeed it be not negative (210).

Figures 12 and 13, Pl. IX, borrowed from the *Publication industrielle* (*) give, the one the motor work, with direct admission of 0,58 at the velocity of 11 miles an hour, and the other the resisting work, at the same notch, at the velocity of 17 miles an hour in *backward gear*, with the injection of water.

It is unnecessary besides to mention that the effort representing the resistances of the vehicle and of the machinery has to be deducted from the mean effective effort on the pistons for the traction, while it is added to that effort for the holding back.

Experiments made on the Saxon State line, in 1870, gave the following results (**).

Four-wheeled passenger engine. Cylinders 16×22 inches. Driving-wheels 5,03 feet. The gear was reversed right over, the regulator full open, and the engine drawn by another more powerful along a horizontal, by the intermedium of a dynamometer, at the uniform speed of 19 miles an hour. An indicator gave the resisting work of the steam on the pistons of the engines drawn.

1*st Experiment. — Injection of steam alone :*

			lbs.	
Effective pressure		in the boiler.	124.87	per square inch.
Mean	—	resistant against the piston.	86.76	—
—	—	motor	16.21	—
—	—	effective resistant.	70.55	

Or 57 per cent of the effective pressure in the boiler.

This trial was effected by the elevation of the temperature, and a damaged stuffing-box.

(*) *Armengaud*, vol. XIX, 1870.
(**) *Handbuch für specielle Eisenbahntechnik*. Vol. III, p. 774. Leipzig, W. Engelmann, 1875.

Effort shown by dynamometer: 2,71 tons. The engine slipping (reverse rotation), it fell to 1.48 tons, to return to the preceding figure, after the closing and reopening of the regulator.

2nd Experiment. — Injection of water and steam :

	lbs.	
Pressure in the boiler	133.97	per sq. in.
Resisting pressure on the piston	84.91	—
— motor	10.80	—
	74.11	—

Or 62 per cent of the pressure in the boiler.

Effort recorded in the dynamometer	2.71	(no slipping).

In *forward gear*, with direct admission at full travel, the effective motor power is 102.4 lbs on the square inch. The *holding back* effort, measured on the pistons, would then only be inferior to the effort of *traction* by 28.30 lbs, or 27.8 per cent.

The resistance of the engine (vehicle and machinery) referred to the pistons being estimated at 17.07 lbs on the square inch, we have for the real efforts :

Traction	102.40^{lbs}	$- 17.07^{lbs}$	$= 85.33^{lbs}$
Holding back	74.10	+ 17.07	= 91.17

So that *at the limits* (valve-motion at the end of the travel in both cases) the holding back effort would exceed the effort of traction by 7 per cent.

Experiments made by M. Guébhard on the Eastern of France, gave, for very inferior admissions, much results smaller, which is quite natural (206, 210) :

Engine with eight wheels coupled, with an adherent weight of 45 tons.

At the 5th notch (admission 0.35) the resistance was 2.46 tons, or 0,40 of the *real* effort of traction in direct running, which is, at that notch, 6.24 tons.

226. *More lengthened admission with counter-steam than with motor-steam.* As we have seen (II. 197), the volume of the cylinders is ordinarily so arranged that the mean effort of traction in direct running, referred to the circumference of the wheels, and deduction made of the resistance of the machinery, exceeds the ordinary adhesion for an admission varying from 40 to 60 per cent of the stroke; and the admission ought to be generally much less, in order to utilize the expansion largely. If, *for the same travel of the slide*, the pushing effort is hardly 0.50 or even 0.40 of the effort of traction, it must be remarked that in reverse running, the travel of the slide is no longer limited by the economical consideration of the expansion, nor by the evaporative power of the boiler ; it is only so by the condition of avoiding slipping, that is to say, by the value of the adhesion. If the latter is great enough, the driver can increase the retarding force by putting the valve-motion at a

higher rate of admission in counter-steam than in forward gear, and reduce the disproportion if not indeed realize the equality of the tractive and pushing efforts.

Diagrams taken off an engine (No. 852) (1866-67) holding a train back on the incline of 1 in 125 at *Etampes*, give an example of the improvement obtained from an admission already considerable, 0.60, to the end of the travel of the slide; the pressure in the boiler being 99.56 lbs on the inch, the mean holding back effort on the two pistons was carried to from 1.9-13 to 2.56 tons.

The diagrams (*figs.* 14 to 19, Pl. IX) were taken also on the *Etampes* incline, engine 852 (1866-67) with six wheels coupled; weight (adherent) 35.43 tons.

Heating surface	1464 sq. ft.
Diameter of the wheels	4.43 feet.
Section of the steam-cock	0.759 sq. in.
Section of the water —	0.043 .

Admissions of steam and water, joint.

Pressure effective in the boiler (atmospheres)	6 1/2	7	7 1/2	8	7 1/2	6
Admission (hundredth of the stroke)	0,18	0,24	0,36	0,46	0,55	0,70
Injection per minute (pounds) — Steam	4,22	4,47	4,73	4,98	6,31	5,63
Injection per minute (pounds) — Water	6,54	6,79	7,04	7,27	9,39	8,72
Velocity (miles an hour)	15,31	15,31	15,31	15,50	21,43	4,9
Effort on the two pistons (tons)	0,314	0,644	0,841	1,337	1,833	2,327

We see how slight the effort is for a small reverse admission, such as 0.18 and it is, without doubt, partly, owing to the injection that it remains positive (210).

Diagrams 21 to 23 (*) Pl. IX, were taken off a far more powerful engine (*Orleans* 8 wheels coupled), receiving much more considerable injections (water only): 39.68 lbs, 28.66 lbs, 39.68 lbs and 39.68 lbs.

On the Northern of Spain, the first water-cocks of these eight-wheeled coupled engines were 0.28 inch in diameter and discharged, under a pressure of 8 atms., 66 lbs of water per minute. This high figure is not necessary in general;

(*) *Mémoire sur la marche à contre-vapeur*, Pl. II.

experience has proved however that it may be usefully exceeded under certain circumstances, and it has been carried to 75 lbs.

The motor work in direct running, and the resisting work in reverse running, acquired by the piston can be calculated, by the principles of thermodynamics.

M. Combes has made this calculation (*) for an engine having a pressure of 8 atms. in the boiler, an admission of 0.458 for the direct stroke and 0.542 for the return stroke, and clearance at each end, equal to 0.05 of the volume engendered by the piston. He found thus, A being the area and L. the stroke of the piston :

I. FORWARD GEAR.

	Direct stroke.	Return stroke.
Motor work	445.313 × AL ft. pounds.	488.378 AL ft. pounds.
resisting —	96.779 AL —	85.494 AL —
Motor work acquired by the piston	348.534 × AL —	402.884 AL —
Total per turn of wheel		751.418 foot pounds.

II. BACKWARD GEAR.

	Direct stroke.	Return stroke.
Resisting work	367.557 × AL ft. pounds.	326.517 × AL ft. pounds.
Motor —	99.281 AL —	100.764 AL —
Resisting work acquired by piston.	268.276 AL —	225.753 AL —

Total per turn of wheel 494.020 foot pounds : that is to say 65.7 of the work in the forward gear.

If instead of deducing these quantities of work from the calculation of their calorific equivalent, that is to say from the quantities of heat lost by the steam in running forwards and gained by it in reverse running, we proceed according to *Mariotte's* law, we obtain respectively 776.740 AL ft. pds. at and 478.007 AL ft. pds. The discrepancy is thus slight, but at the same time the expansion is low. Now, without going down nearly as low, in locomotives, notwithstanding the actual elevation of the pressure in the boiler, as in many stationary condensing engines, the admission is ordinarily reduced to $\frac{1}{3}$ and often below ; and then the application of *Mariotte's* law would give nothing but a rough approximation ; if the great wetness of the steam did not come in to compensate, or rather to cover in part, the inexactitude of the law. We shall return to this point in investigating the useful effect of the locomotive.

(*) *Études sur la machine à vapeur*, p. 123. *Dunod*, Paris.

Admitting that for a certain travel of the slide or the same notch for both gears, the effective resisting effort is only 0.60 of the effort of traction, the force necessary to retain on the incline $\frac{I}{i}$ the train P of resistance r, that is to say $P\left(\frac{I}{i} - r\right)$, less than the effort of traction in ascending, $P\left(\frac{I}{i} + r\right)$ may be greater than 0.60 of that effort, and in that case the counter-steam is insufficient.

227. *Influence of the velocity on the holding back force.* Drivers know perfectly that counter-steam has little effect on a train at high speed. The high speed exerts a common influence on the *holding back* as on the *traction*: it increases the fall of pressure at the passage of the ports; but there is further, and in the same direction, a special effect in reverse running. The slide has the same velocity at the moment when the direct admission commences, and when the reverse admission commences, seeing that it then occupies two positions very nearly symmetrical on each side of the middle of its travel. But the velocities of the piston are very different in the two cases. In the first, the piston commencing its stroke moves very slowly; in the second it moves very fast. The establishment of the *regime* pressure in the cylinder requires a certain *absolute* time, during which the piston runs through distances which are greater, in proportion to the velocity of rotation; but, for direct admission, it has only run through, even at a high speed, a small fraction of its stroke when the steam acts fully on it, while in reverse running, it has then only a little distance to travel, and consequently little work to destroy when the full pressure is established.

It is therefore prudent to reckon less on the counter-steam, the higher the speed is, and this is a further reason for avoiding all excess of speed.

Frequently overestimated, the power of the counter-steam is on the contrary too much depreciated, even by practical men.

"This apparatus, in my opinion" says an experienced locomotive superintendent, and one in an excellent position to follow up the use of counter-steam, "is only good for checking the velocity of trains running down inclines; but I cannot admit that it can be employed for stopping the trains at all the stations. It is besides not very energetic, and *its use should be prohibited at a moment of danger, for it would be far from producing, as resistance, the effect of the counter-steam in the manner which drivers used to apply it.*"

This last assertion is quite incorrect (203-204). In the face of danger, the

driver reverses right over; he pays no attention to avoiding reverse rotation, nor indeed to injection. He does exactly at the present time what the drivers did formerly, before there was any question of this injection; and he does it better, and more surely, thanks to the screw, and to the more general and better understood use of sand.

In acquainting the London Institution of Civil Engineers vith some trials of counter-steam at which he had been present on the *London and South Western*, M. *Bramwell* (*) cited a fact which he observed, not without surprise: that the indicator recorded, during reverse admission, a higher pressure in the cylinder, than in the boiler. « It was at first thought », says he, « that the indicator was out of order, but, it was tested and found quite correct. » The excess observed was thefore attributed to the inertia of the current of steam losing rapidly in the cylinder the great velocity it possessed in the induction-pipe.

Admitting the explanation, it would not be sufficient to account for the great discrepancy recorded: 18,5 atms. in the cylinder and 8.4 in the boiler.

But, excepting the numerical values, variable with the diameter and arrangement of the tubes and the speed, the fact is general (diagrams of Pl. IX), and necessary. In forward running, there is during admission, a fall of pressure more or less great from the boiler to the cylinder; in reverse running, there must certainly be, during the forcing into the boiler, a fall of pressure from the cylinder to the boiler, seeing that the discharge is in that case from the first into the second : without that excess of pressure, however, the inferiority for the same notch of the holding back effort in direct running would be still more marked.

People often let themselves go wrong with regard to the consequences of this principle, that the reduction of volume of saturated steam cannot raise its pressure; a principle which would be correct if the heat due to the compression being withdrawn, the temperature did not rise; but this is by no means the case, either in the present instance nor in the others.

228. *Running with counter-steam is not new.* It is often believed that running with counter-steam, without reversing the rotation, has only been known for some years, that the fact and the name are recent : this is an error. Both the one and the other have been since the very origin of

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(*) *Minutes of proceedings.*

railways, familiar to every locomotive staff as well as to engine-builders (*). only, counter-steam was used very cautiously for the reasons which we have set forth (217).

The injection of steam and water, or of water only, allows reverse steam to be applied, not only for very sudden stoppages (cases which are luckily rare, and which required only the substitution of the screw for the lever) but also in regular service. Notwithstanding the simplicity of this complementary operation, it is often objected to as being too delicate in the application. Frequently also, it is the principle which is attacked, either with regard to the relative smallness of the retarding force which it originates, or to the insufficiency of the injection of water for protecting the cylinders from the effects of the heat disengaged. M. *Ramsbottom*, who applied it twenty years ago to twenty engines on the South Wales district lines, gave it upon this latter account; and his successor, Mr F. Webb, after fresh trials, followed his example.

Mr *Tomlinson* (**), locomotive engineer of the Metropolitan Railway, goes farther; he condemns absolutely the application of reverse steam, at least in that shape, and greatly prefers the ordinary brake acting on the wheels; the reverse steam, only acting on the piston when it is towards the middle of its stroke, and consequently animated with a high speed, imparts thereto, according to that engineer, shocks which are destructive to the whole machinery. His objection might have been made *à priori*, but it is difficult to maintain it in the presence of facts which formally contradict it, at least for engines kept in good order. Admitting that on the Mediterranean lines, for example, an error has been committed in applying the injection to all its engines, would that be persisted in to the detriment of the whole of the machinery?

Reverse steam is not irreproachable; no one contests that. Hence the different attempts made, either to improve the details, or to utilize, under forms more or less varied, the machinery of the engine, as means of

(*) *Annales des Mines*, 5 th series, vol. VI, 1854, page 395.

M. Beugniot described in 1859, running with counter-steam, and gave the plot of it in the *Bulletin de la Société industrielle de Mulhouse*, vol. XXX, page 497.

" This property of reverse gear or running with counter-steam with locomotive engines has been remarked from the commencement of the service of these engines," says the minute subjoined to instruction N° 104 (12th June 1867), of the Mediterranean locomotive department, " and since that time the use of counter-steam has been recommended, and rules laid down for it in order to obtain the prompt stoppage of trains in presence of an obstacle. Unfortunately, there were considerable obstacles to the employment of this means. These disadvantages must be divided into two classes : the first relating to the reversing gear, the second to the consequences of reverse running. "

(**) *Minutes of proceedings*, vol. XXXVIII, 1873-74, p. 48.

stopping. Before proceeding to investigate these attempts, we must stop to remark on some facts of another order, which refer to the application of the injection.

§ VIII. — Digression on some incidents to which injection into the exhaust has given rise.

229. This application has been the subject of a lengthened dispute between two engineers then attached, the one as chief of the locomotive department of the Northern of Spain, and the other as consulting engineer to a financial company which, after a rapid fall down the steep slopes of the *Tarpeian* rock, lately attempted under the same name, but under different colours, to reascend the Capitoline.

The matter was altogether a personal one, a question of priority.

After having discoursed to the Academy of Sciences (*Paris*) at its meeting of the 15 July 1869, on running with reverse steam, the late M. *Combes* (*) added :

" I have wished and I wish still to remain completely unconnected with this dispute, in which the Academy would doubtless no more desire to interfere than I."

A wise caution, which it would have been well to follow, the more so from the competence of him who gave the example.

We have no desire to mingle in a dispute, which was besides terminated by the death of one of the opponents, from whom however we shall take almost all the elements of the following account.

To every one but the two adversaries, this personal quarrel was a little matter, and a discussion on this point would under no circumstances be in its place in this work.

But there arose, on the occasion of this small affair, other matter and something more serious in itself than the grounds of the dispute.

Setting the latter on one side, avoiding indeed scrupulously comment thereon, it is of importance to bring out incidents, forms of interference and summary proceedings as regrettable as unexpected; it is of importance especially to prevent a repetition of ways and proceedings calculated uselessly to prolong personal discussions, and to lead opinion astray. The questions often addressed to us on this subject prove besides, that in the eyer of a considerable number of engineers, it has a certain interest.

After an exchange of publications in which fortunately, the controversy,

(*) *Compte rendu de l'Académie des sciences.*

while occupying a great place therein, left here and there room for useful technical observations, one of the adversaries proposed (*) to put the decision of the matter into the hands of competent arbitrators, named by the two parties, and whose verdict should be accepted without appeal.

Some days before, the other adversary had expressed himself thus in one of his publications (**).

In order to reestablish the equilibrium between M. *Ricour's* publication and mine, I was preparing to bring out a new edition of my last paper (*Supplément au mémoire sur la marche à contre-vapeur*) when a new circumstance took place:

"Several railway companies, on the very occasion of the new publication of M. *Ricour*, thought proper to address to me official testimony which, by their authority, settles the question of priority and dispenses with my continuing the controversy raised by that engineer."

Strong in this spontaneous aid, without doubt, and which at all events seemed to come so opportunely, M. *Lechatelier* rejects in these terms the proposal of arbitration:

"I cannot accept *in any respect or under any form* the proposition you submit to me. This question to which you allude is not within the scope of the *Mines* or of the *Ponts et Chaussées*. It is solely a question of practical mechanics, and I consider it as definitively disposed of by the recent expression of *its most competent judges*." (***)

Its most competent judges? These judges, appointing themselves by their own authority, judging without mandate, without hearing the parties, without cross-examination, were they at least the locomotive engineers of the railway companies? No, they were... the Boards of directors!

They were the chairmen, M. *Emile Pereire* at their head, declaring that "*the question of priority seemed to him disposed of*" a point on which besides, "*the board had had no doubt* (****)," then his colleagues, not less honourable than incompetent, of the five other principal companies.

An assembly may doubtless be called on accidentally to elucidate questions foreign to its ordinary duties. Thus one day, at *Rome*,

"The senate put to vote this affair important,
And the turbot was done with sauce piquant."

(*) Letter from *M. Ricour* to M. *Lechatelier*, dated May 19 th 1870.

(**) *Marche à contre-vapeur. Question de priorité.* Pamphl. in 8°. Paris, April, 1870, page 5.

(***) Letter of the 22 nd Mai, 1870.

(****) *La contre-vapeur employée comme frein. Déclaration,* dated the 6th of June 1870, of six *inspecteurs généraux* of the *Ponts et Chaussées* and of the *Mines,* with reference to the opinions expressed by the Boards of direction of the six great companies. *Oberthur et Fils.* Rennes, June 1870.

In that case, there was nothing to be said; it was the case of a Board probably very competent and, in any case, regularly occupied with the question at issue.

But to fancy railway directors deliberating on, or at any rate, deciding the question of counter-steam? What could it possibly matter to them, to these men almost all absorbed by occupations of quite another nature, whether the idea of injecting into the exhaust, of steam and of water, or of water only, belonged to Peter or to Paul, or to neither? This is what we shall shortly see; we shall soon discover the tip of the ear peeping out from under the lion's skin.

To the certificates of the six companies, six *inspecteurs généraux* of the *Ponts et Chaussées* and of the *Mines*, who, some by their position, all by moral obligation, had studied the publications connected with the controversy, opposed a *declaration* in which, taking great care not to constitute themselves judges on the merits, they urged the strangeness of the proceeding, and of the evident, virtual nullity of testimonials delivered under such conditions.

The *declaration* stated :

"This result" (a net solution, fixing the legitimate part of each) "it would be easy to obtain by submitting the dispute to arbitration. The two parties would be called upon to offer their explanations, to produce such new documents as would appear useful, and to bring forward, if required, special men, either as to details of pure practice, or on the scientific principles involved in the question.

"The decision which would then be made by arbitrators of unquestioned impartiality, as are easy to be found, as well in the two corps of engineers as outside, would be imposed with an authority that no one could challenge.

"We ascertain that M. *Lechatelier* refuses this.

"He considers the question as definitively settled in his favour by the letters which he has received from the directors of our great railway companies, with reference to which he is officially charged with the mission of studying the use of counter-steam.

"*Is it thus that an inventor acts, sure of himself, of his rights, and of the want of grounds on the part of the contrary claims, at the risk of seeing his refusal interpreted against him? Does he not rather meet a serious inquiry, attended with every guarantee in such a way that it may lead to the entire manifestation of the truth?*"

The *declaration* concluded in these terms :

"We do not hesitate to declare that, in our opinion, testimonials published without corroborative proof, have had no effect on the position of the dispute, and that M. *Lechatelier* is in no way warranted in taking advantage of them in order to consider the question decided in his favour."

Paris, June 7th, 1870.

230. To decide on a question so delicate as one of priority, and that without a mandate, without competence, without any recital of the facts, was serious; more correctly speaking, it was... thoughtless. We shall state directly (231) under the empire of what preoccupation, legitimate in our eyes in its principle, the railway boards allowed themselves to be led into an act without precedent, and the objectionable side of which was up to a certain point screened by this predominant preoccupation, in the eyes of men so ignorant of the question which they took upon themselves to decide, and for whom the grounds of the personal dispute were a sealed book.

It was so easy, however, to spare themselves this inconsiderate step. And if, notwithstanding all, it was desired to go into the grounds of the contestation, a moment's examination was sufficient to show the necessity of doing so with a very light hand, with great prudence, at the risk of compromising everything by calling attention to details which had remained so far disregarded.

If the engineer actually affected by the singular sentence of the *extraordinary* tribunal, deceived himself in believing that he had invented something in the application of counter-steam, has not his error been shared? Has it not been so, particularly and in the highest degree, by the very one who complained so bitterly of him afterwards, and who gave another name to that error?

It was sufficient to glance over the papers published, in order to find these testimonies :

1 st. Letter from M. *Lechatelier*, dated March 3rd 1866, to the director of the Northern of Spain, M. *des Orgeries* (*) :

According to the few words he writes you (M. *Ricour*), I understand that by means of a small tube carrying a cock, open only during the reverse steam, he *puts the blast-pipe in communication with the interior of the boiler itself;* the cylinder has no longer recourse to the atmosphere but to the boiler itself, and then there arrives in the cylinder air mixed with steam. In this way a complete current is formed between the cylinder and the boiler, *the regulator being open, instead of being shut as in my primitive combination ;* and in the upper part of the blast-pipe, which remains in communication with the atmosphere, a volume of air is maintained which remains still, or at least oscillates little.

If this is, in effect, the solution, I find it very simple. But before anything is done on a large scale, I should be happy to have a precise word of explanation from M. Ricour, to confirm what I describe above, if I have duly understood, and to give me more detailed

(*) *Mémoire sur la marche à contre-vapeur,* par *M. Lechatelier.* — *Paris, Paul Dupont.* 1869, page 206.

explanations of what M. Ricour desires to do, if I have misapprehended his intention. Have the goodness to convey my desire to him.

M. *Ricour* hastens, by his letter of the 8th March 1866 (*), to inform M. *Lechatelier* that he has quite understood, and to give him « in accordance with the desire he has been so good as to express, » more detailed explanations.

On his side the director of the company, M. *des Orgeries*, being on the spot, wrote on the 29th March 1866, to M. *Lechatelier* (**) :

The last letter from M. *Ricour* has informed you of the *complete success at which he has arrived by the use of counter-steam. This is a very great result, which will allow us to effect important economies, while giving us an increase of guarantee and of security.... The new and important service which M. Ricour has rendered, ought to be the opportunity of putting him into a less unfavourable position. In any case, and in whatever way the company may reward this service, it appears to me that it could not see any objection to M. Ricour reaping advantage from the application of his idea to the other Spanish companies. For France, it may be otherwise, and perhaps it would be better for his system to be presented to* the government (French) as an improvement freely offered to the railway interest. It is, however, spontaneously that I submit these reflections to you. »

3rd The future opponent is not less inclined to be agreeable. After doing justice to the merit « of the solution », which he finds « very simple », he takes up the interest of its inventor.

Letter from M. *Lechatelier* to M. *des Orgeries*, dated March 12th 1866.

"I think it desirable that as soon as M. *Ricour* has made a definitive trial, and the result is quite certain, he should write a report on the subject. I will submit this report to the council in order to make known to them the results obtained, and will get myself authorized to send it to the Minister of Public Works, who will have it examined by the commission on brakes, inventions, etc. *This will be a good point in M.* Ricour's *mémorial to the Office of Works etc.*

Every thing is thus all right for M. *Ricour*.

But soon the language changes and the strife commences. A sort of compromise intervenes, but the truce is soon broken; the friendly disposition with regard to the inventor of the « *very simple solution* », of the « *very good idea* », of the « *lucky idea* » is at first softened down, and then formally disavowed :

At the outset of this new phase, it was only the question of *sharing;* this idea was even expressed with some diffidence :

(*) *Mémoire sur la marche à contre-vapeur*, by M. *Lechatelier*, p. 207.
(**) *Supplément au mémoire sur la marche à contre-vapeur*, Paris, *Martinet*, 1869, p. 100.

Letter from M. *Lechatelier* to M. *des Orgeries*, dated April 10th 1866 (*) :

"But I do not believe that the final result can be separated from the starting point, or from any intermediate one. *Without seeking to measure the part of each, it seems to me that his* (*M.* Ricour's) *has no more importance than mine. If a patent were to be taken out, it should be taken out in our joint names*, or, more strictly speaking, in the name of the company."

Let us go on to 1869. Ah! then, it is no longer a question of *sharing*. *Mémoire sur la contre-vapeur* p. 180 :

"It never once occurred to me, the correspondence shows it sufficiently, to refer to my previous letters, which were disseminated amongst the numerous copying books.

"It has so happened, consequently (?) that *I have attributed on several occasions to M. Ricour what was, in reality, only the reproduction of my own ideas.*"

Some lines lower, same page :

I reply, September 19th, 1865, *without paying attention to the fact that there is nothing therein but a new version of my own ideas.* I believe that M. *Ricour's* idea, of bringing the steam into action is very good."

And again some lines lower down, on the same page :

" In replying on the 3rd March 1866 (to M. *Ricour*), I allowed to be sent, *with my signature*, a letter (*) prepared by a third person, *which makes me attribute to M. Ricour the merit of this combination, which I had wholly furnished.*

"The letter of the 8th March, in which M. *Ricour* gives me more circumstantial details, *does not dispel my illusions on this subject*, and the 12th March, I write a letter (No. 13), *which appears to have been drawn up under the same influence.*

"The next day, I write to *Vienna*, to the director of the Austrian Society, to get him to make experiments, telling him that the starting point was the trial of M. *Debergue's* compressed air brake, and that it is M. *Ricour who has had the lucky idea of bringing the steam back into the boiler, instead of losing it in the atmosphere.*"

"I write in the same way to M. *Flachat*, the 28th March, begging him to make a communication on the subject to the Société des Ingenieurs civils.

" *My memory had served me badly, and I hastened to render to M. Ricour testimony which the illusion produced by his correspondence caused me to consider at that moment, as the expression of the reality.*"

Elsewhere (*Supplément sur la marche à contre-vapeur* (**), page 5) the author emphasizes more still, if possible, this particular phase in which he was so far from being conscious of his invention :

« I will remark that this line of argument of M. *Ricour* rests in great part on fragments of a correspondence broken by long intervals, during which

(*) This is the letter, reproduced above, page 459.

(**) Paris, *Martinet*, 1860.

I have several times lost sight of the instructions which I had myself furnished, so that by forgetfulness, and dictated besides by a feeling of consideration easy to understand, *I had on several occasions attributed to M. Ricour ideas which I had produced previously in the clearest manner.*

Strange phenomenon! who will undertake to analyze this remarkable action of the mind, by which an inventor, so long unknown to himself, an inventor without knowing it, discovers at last, when the *psychological* moment has arrived (let us hasten to put down this expression while it is still in fashion), that he was mistaken, that it is he who is the inventor and not the other!

The latter however preserved a modest but useful part:

Letter from M. *Lechatelier* to M. *des Orgeries*, dated May 5th 1866 (*Mémoire sur l'emploi de la contre-vapeur*, page 184).

"I am far from denying M. *Ricour's* merit, and the services which he has rendered in this circumstance, by following up, from the outset, with interest, these trials, later, by personnally directing them, and deducing successively from the results of the experiments the consequences which might be developped by discussing with *intelligence* and *shrewdness* the given quantities of the problem in order to obtain the complete solution of it."

But soon, like those which have preceded, this view gave place to another, absolutely contrary. The author of the « *very simple solution* », of the « *lucky idea* of the return of the steam into the boiler » had become a simple instrument, but at any rate an « intelligent, shrewd and deserving one ». He does not alas! long enjoy that honourable mediocrity. Every thing taken into consideration, he has been, in reality, only an obstacle, complicating every thing, understanding nothing:

Supplément au mémoire sur la contre-vapeur, page 47:

"The personal intervention of M. *Ricour* has given quite another direction to the experiments, and in his hands, the question became so complicated that he had not yet managed, in May 1869, to render an exact account of the effects produced."

Down such a hill, notwithstanding the subject, there is no stopping.

The same Supplément, page 84:

"I do not hesitate to express the opinion that *no merit for execution* can be attributed to M. *Ricour*, and the conviction that without the French railways, and the Paris and Lyons line in particular, *the counter-steam would have collapsed in his hands.*"

The same Supplément, page 10:

"In my first paper, I contested all participation in the invention with M. *Ricour; now I contest to him all merit of execution in the investigation in which he took part;* and I do not fear to assert that an intervention, to which the chance of positions

alone has given rise, *has been the cause of lengthened delay in the preliminary trials and in the application, and by the trouble and want of clearness which he has spread over this simple subject, he would have seriously compromised its success if other engineers of more experience, and unbiassed by any preconceived views had not carried it out successfully.*"

What a distance passed over! what a fall! What has become of the « very simple solution, the lucky idea, the services, the shrewdness, the merit » which were so ready to be acknowledged? What has become of the « good point » in the brief?

Once more, it is no question in this case either of inventor, or of priority. We do not know, and we do not wish to know who, at bottom, is wrong, who is right, and to what extent. What is evident, is that he who has run through so complete a scale of views as we have just read, has absolutely deceived himself in one of these two extreme and contradictory phases of his evolution. Is it in the first? is it in the second? In the letters of 1865 and 1866, or in the pamphlets of 1869 and 1870? Who knows? What do the authors of the six testimonials know of it?

As to his good faith, it is out of court. Is any other proof necessary that that ingenuous turn with which he repudiates his preceding declarations, when light at last broke in on his mind, and the truly paternal, repentant feeling with which he recognizes his invention, the day when, clearing up his ideas hitherto misunderstood he comprehends them and perceives a little later that he had been mistaken; that he *had produced them previously in the clearest manner,* » which had not prevented him from « *attributing them on divers occasions, to M. Ricour* ».

This is what, as circumspect men, the directors of the companies should have, before everything, looked at and weighed, seeing that they wished to constitute themselves judges. They would have understood that if an inventor could mistake to this point his own invention, his own ideas, and formally attribute them to another, that other was certainly to be excused for sharing the error, and for not having at the end of the account, his eyes opened just exactly at the same moment.

231. And now, what could have been the *motive* of the *testimonials* which have ended in shifts and turns so strange, so contrary to the habits of inventors for whom ordinarily their inventions have passed into the state of fixed ideas, which possess and follow them everywhere?

The evasions, they were ignored. It was sufficient to read, to run through the documents published. That indeed was the question! The real *motive*, the real meaning of the testimonials, is a *protest*. Against whom? against

what? Against the abuse of patents. We have already said (106, note) : no works of industry find in the same degree as railways, the obstacles of certain patents. They are so rich, people say, a patent right! what is that to them? With artifices, cleverness of style, the descriptions but too often turn out regular hornets nests. The special talent of a concocter worthy of the name consists in putting in not only the fact acquired, the invention good or bad, but also the future inventions and improvements, which a word put in its place can cause to fall into the nets of the patent. It may thus be conceived how the very name of certain patents inspires the companies with a sort of dread. They wish to pay only what they owe, and to whom they owe it, in which they are perfectly right.

This feeling is much stronger, if it is a question of patents taken out by persons belonging to the companies, and of work done in the exercise of their duties.

Nothing can be more just. A work done, a result obtained by bringing into operation the resources of every kind which the stock of a railway company offers, with the regular cooperation, obligatory of its technical staff, belongs to the company. If the inventor has the greatest share of merit, he cannot assuredly pretend to reap directly, as a private individual, the material benefits, as does an isolated inventor, working on his own account.

Now (*) a patent had been taken in Spain, the 3rd Dec. 1866. Although this was not done in France, the companies could not but feel themselves seriously threatened by the intention, followed out or not. On this ground, a protest on their part was thus legitimate and natural. But it should have gone straight to the fact considered as an abuse instead of dissimulating it behind a question of priority, of property.

The patent taken out in Spain was moreover not the only one. Another had been taken out in Belgium the 25th. April 1866, in the name of M. *Michel Bourson*, inspector of rolling-stock on the Northern of Spain line, who had studied in all its aspects, and with much intelligence, the question of counter-steam.

M. *Bourson* takes great pains to establish « that *he had found out by himself, the complete solution, at the date of the 24th Feb.* 1866, » that is to say at the period when M. *Lechatelier*, rightly or wrongly, had not yet dreamed of contesting the invention with M. *Ricour*. It is not a question, certainly, of discussing here M. *Bourson's* titles; his entrance into the lists was not at first regarded very unfavourably, if we may judge from this pas-

(*) *Supplément au mémoire de la contre-vapeur*, p. 103.

sage in a letter addressed by M. *Lechatelier* to an eminent director of the « Credit Mobilier » (*) :

« It is essential that M. *Bourson* should not get into any dispute with his superiors, in which he would have against him the dates of official documents. *It would be easier to have justice done to his part of the cooperation, of initiative*, than if he demands it, in deceiving himself on the real and legal value of his pretensions to priority. »

Some days afterwards (14th of May 1866) a letter from the same to the same, had:

« It is most essential that M. *Bourson* keep quiet. »

M. Bourson kept « quiet » a very long time, without result. Later, he ventured on some claims; they had the same success, and the affair rested there.

The directors of the companies, had, without contradiction, like every one else, seeing that the papers of the case had been published, the right to form an opinion on the question of priority, and even to state it; but under the condition of supplying these proofs, of making known how their conviction was arrived at, on so special a matter, and touching rights which, for so long a time had not had the simple notion of their existence.

232. It was wished to give a lesson for the past, a warning for the future; but the form is unfortunate, and the lesson without bearing, because it is without right, without justice.

The companies are of the *Sosia* school, for whom

« The true *Amphytrion*,
Is the Amphytrion where one dines. »

For them, the real inventor is he who claims nothing; a *criterion* which would not always be of convenient application.

M. *Lechatelier* said very justly (**) :

« I consider that our position, as engineers belonging to the great railway companies and, at the same time, to the administration of the *Ponts et Chaussées* and of *Mines*, does not permit us to take out patents on a subject which enters directly within the scope of our professional duties. »

But was this engineer after all, as strict as we as regards patents taken out

(*) Letter of the 11th of May 1866.

(**) *Supplément au mémoire sur la contre-vapeur*, Letter already quoted to M. *Des Orgeries*, page 101.

under such conditions? It would appear not: for after saying not less justly (*).

« It never entered my head... that I could make experiments at the expense of a company, to apply the advantage to myself, by a patent, in France or abroad. »

He adds:

« *I have perhaps been wrong in not thinking of it for the counter-steam.* The Northern of Spain company would certainly have given me the rights, under certain stipulations for freedom therefrom, for the companies connected with it. The consent of the Public Works Office would have probably been granted, if i had asked for it. I should have taken out a patent on *the 28th of July* 1865. I should have completed it by a formal addition on the 19th of Sept. following and it is likely that M. Ricour, seeing the companies obliged to pay me for the use of a legitimate and incontestable privilege, would leave me to day to my affairs and my studies.

In 1865 it was a little too soon to think of this patent. At that period, and even later (*letters of 3rd and 12th of March* 1866), it was still M. *Ricour* who had found the « very simple solution » (229).

233. The six testimonials from the six companies are contemporaneous, and, as may be imagined, of the same block. They all express to M. *Lechatelier* « their gratitude for the disinterestedness with which he has put his discovery at the service of the public. Thus to all applies that passage of the *declaration*, or more correctly speaking, of the simple exception taken by the six *inspecteurs généraux*:

« No one will certainly admit M. Lechatelier's pretensions to have accepted in the character of a definitive judgement the eulogistic testimonials handed to time by the directors of the companies, *especially touched*, as may be imagined, by *the gratuitous permission to apply the system.* »

In one of the testimonials (that from the Southern), these words occur, which bring it out a little from the rest:

« The board of directors has decided, after lengthened experiments, that a very large number of the company's locomotive engines shall be provided with the system of steam-brake established according to the arrangements which you thought of, *and which we have copied from the Mediterranean Company.* »

The locomotive department of the *Mediterranean* was in effect, the first in France, which applied the injection to running with reverse steam; and it was done with great care, and with the decision which triumphs over difficulties and routine.

(*) *Supplément au mémoire sur la contre-vapeur*, page 97.

But these arrangements which were copied, whence had they themselves been copied?

The *Mediterranean* engineers were aware of the injection of steam and water, only through M. *Ricour*, paper already cited (219) on the application made in Spain. These engineers anxiously desired to have it communicated to them as soon as possible. The writer of these lines had at that time, in pursuance of his duties, the manuscript in his hands; he communicated it to them, and to them only, before printing; that paper was their only guide, and the (autographic) note *on the use of reverse steam for moderating the velocity of trains*, of the locomotive department, dated the 24th of Dec. 1866, says (page 4):

« We have had the fortunate opportunity of going minutely over this paper, which is to be published shortly in the *Annales des Mines.* »

The printed note annexed to instruction 104 of the same service and dated the 12th of June 1867, is thus expressed (page 14):

« Two modifications imagined to attain this object have been experimented on lately, on the Lyons line. The one « (the screw) », relating to the other reversing mechanism existed on English engines; the other « (the injection) », relating to the use of the reverse steam itself, *came to us from the Northern of Spain.* These two modifications have allowed us, in all the experiments made hitherto, to *avoid all the drawbacks of counter-steam pointed out above.* »

Thus, and that according to those who made the first and most important application in France, the solution « which allowed all the drawbacks of counter-steam to be avoided, came from the *Northern of Spain.* » It is of no consequence to whom it was due; it came thence, that is a point beyond contestation. M. *Lechatelier* recognized it at first: « the solution of the problem » says he, « was obtained in 1865-66 on the *Northern of Spain* » (*Mémoire sur la contre-vapeur*, page 9).

But farther on, he says (same paper, page 95): « fortunately *other ideas* prevailed on the French lines, at the time of the application of the counter-steam. » This hardly agrees with the statement of the *Mediterranean* engineers. What *ideas* were they? Would it be as to the relative proportion of water and steam, a ratio essentially variable, which the driver regulates it each moment according to the effects which he observes during running?

234. The point that could be made from the point of view of the question

of priority, of the fact which serves to draw the boards of the companies into the dispute, had been easily conprehended.

It was not a direct argument in the cause; it was much more; it was one of those *side* arguments, often more powerful than reasons; and particularly easier to understand without any trouble; it was a *weapon*.

Thus we see this fact figuring in a communication addressed to the Société des Ingénieurs Civils (*Paris*), (meeting of the 7th of May 1869), in language fortunately rare in discussions of engineers (*):

« It was on the very railway where this programme should have been followed up with the utmost earnestness, that there took place a regrettable stoppage.

« .... This was due to a preconceived idea, to a systematic direction given in consequence to the trials which, in the middle of a period of guess-work, fixed in a premature manner, for the use of the mixture of steam and water, arrangements which could not attain the object. *This became explained subsequently, by the taking out of a patent by the person charged with carrying these trials out, an underhand proceeding carried out in spite of the formal* intention expressed on several occasions by M. *Lechatelier* and by the Northern of Spain company to hand over to the public the results of that useful experiment. In consequence of damage, difficulties and dangers in the working of the reversing lever, the use of counter-steam fell almost into abeyance, on that railway of all on which it would be of most advantage, on account of the steepness of its gradients.»

The « very simple solution » became « a regrettable interruption »; in 1867, the solution came from the *Northern of Spain;* in 1869, it came from elsewhere, and in spite of the *Northern of Spain;* the engineer who was praised for it, and to whom were addressed all the testimonies quoted farther back (230) has become « a person charged with following out the trials », and who does an « underhand act ». Ever the tip of the ear peeping out.

« That » became explained (as said the author of the lines summed up by that word) by the « *underhand act of that person* »? The reader will decide this. But what that word explains at least, if it does not justify them, are the six declarations of the boards of directors.

Right feelings are to be respected, even to exaggeration. The author we have just quoted was fond of patronizing; no one interested himself more fully in the works of those with whom he was connected by long fellowship; no one extolled them with more warmth. He was pleased with their praiseworthy ambition to distinguish themselves by useful inventions, and at need when they did not make any, he attributed such to them officially. This was done by degrees, almost involuntarily; the name of the inventor, quoted at

(*) *Compte rendu of this meeting,* page 96.

first, gradually disappeared to make way for another, who remained master of the field. Who does not remember the application of balance-weights to locomotives (II, 278 and following), and up to the admirable experiment of M. *Nollau* (II, *Additions*, p. 856) so liberally granted to an engineer who, in order not to disoblige so kind a colleague, allowed it to be done?

235. That the official decision of the directors passed (who doubts?) with overpowering unanimity, and was pronounced sound and valid, by the one for whom it endeavoured to gain the cause, may be granted. The dispute once being declined (229), perhaps silence was more desirable than this sham, this sort of decree of the *council of Ten*. It is a matter of taste. But what is scarcely comprehensible is, that it should have been accepted thus, the eyes shut, as the sentence of a sort of souvereign court, by special writers, addressing a competent public, indifferent enough as to the dispute itself, and who besides had the right to believe in all safety of conscience, that it might rely on them in the matter.

It is convenient, without doubt, to accept ready made judgments. But at the same time, it is right to know in what circumstances they have been interposed, and what they are worth at bottom. Who wishes to teach and judge, has no right to ignore anything, especially when ignorance may conduce to injustice. Authors have however been known to outdo the certificates of companies, and rise even on this subject to a sort of lyricism.

If, which we take good care not to dó, we had wished to express an opinion on the merits of a controversy, to which in itself we were quite indifferent, we should have looked on it as a duty to form it on a study of the documents, and to set forth their grounds. But one sole point gave it importance in our eyes : the abuse of influences foreign to the domain of purely technical and scientific questions, to which that domain should be strictly interdicted. The more powerful these influences are or may become, the more necessary it is to defend against their encroachment, principles which should be maintained intact, of common accord.

And if, reduced indeed to quotations drawn, its had been seen from what source, the defence takes, by the force of circumstances, somewhat the air of an attack, whose fault is it?

Gratuitous assertions, which by themselves prove nothing, may at times, when they are placed by the side of what their authors could and should know, prove something : a mind already made up.

We could thus not shrink from a recital, which, in spite of its length, will not have wasted either the reader's time or ours. These things had to be

said, and it was desirable that they should be so, in a book addressed chiefly to readers for whom questions of personal dignity have no less interest than the questions of their profession.

236. A recent fact rendered this statement more necessary still. The jury of the Exhibition of 1873 at Vienna decreed to M. *Lechatelier*, a diploma of honour for the injection into the exhaust, in running with reverse steam.

The jury thought, and with reason, that there was a useful improvement therein, worthy of a high reward.

In the matter of Exhibitions, the rewards are given, in general, not to an abstract individual, but to a name; the jury rewards the fact in the person of him who, were he a non-exhibitor, is or seems to be the inventor. The jury can scarcely proceed otherwise. But if a question of priority, of property is pending, the act of the jury, who judge the fact and not the right, has, *on this point*, exactly the same value, the same bearing, neither more nor less, than that of the six French companies. It testifies to one thing, the value of the improvement. As to the other question, it is by proofs only that it can be settled. The extent of personal relations, compliant and inconsiderate evidence, and the influence of affairs, can produce no effect therein, fortunately.

The Vienna jury would besides have acted better by doing, in this case, what it did in many others, that is to say awarding the recompense to a collective, and indivisible individual. In this case, the individual was quite naturally pointed out : it was the Northern railway of Spain.

This is the course which without doubt the jury, if better informed, would have taken; it certainly was not for them to give instructions for this case; they neither had the means nor the right so to do. But it is evident that the documents which precede, remaining confined within a tolerably restricted circle, had not come to their knowledge.

Those who, perchance, might desire to clear up this conflict of rival pretensions, would have to put into the scale rights of M. *Ricour*, who lays claim to the invention; of M. *Lechatelier* who conceded it to him first of all, than withdrew it in order to take it to himself; of M. *Michel Bourson*, to whom M. *Lechatelier* seem to allow a share, indeterminate (230); of M. *Steinmetz*, head of the *Alicante* depôt, who, according to M. *Bourson* (*), « is the first inventor of the counter-steam apparatus », etc....

(*) I send you herewith the copy of a letter from M. *Steinmetz*, head of the *Alicante* depôt, which shows that person may be partly considered as the first inventor of the counter-steam apparatus. Letter from M. *Bourson* to M. *Lechatelier* : *dated the 5th of May*, 1860. *Valladolid.*

Do we not seem to be here in presence of a collective work? is it very certain that those who have participated in this work in common, would not themselves be, at bottom, greatly puzzled to distinguish exactly the part which is really due to them?

237. A word further, and quite in a historical interest.

Let us first call to mind a principle, which appears to be beyond contestation. If the real inventor is he who first emits an idea, and tries to carry it out, it is only an incomplete inventor who allows himself to be too soon discouraged by difficulties of detail, and does not arrive at the application of it. If, from a certain point of view, there is more merit in him who renders the idea really practicable, it is especially this latter who has rendered the service, or at any rate the two acts are inseparable.

It often happens, however, under the influence of new circumstances that questions, given up because they were not matured, are taken up again later on. This is what took place for the complement of counter-steam without reverse running. It was particularly the extreme traces imposed by increasing exigencies of the nature of the ground passed through, which brought it out of the stagnation period, although in fact its application to steep gradients is much less general than is often supposed.

The first trials of the injection of water go back to 1855. We read in a letter addressed by M. *Lechatelier*, the 27th of April 1870, to M. *Flachat* and communicated by the latter to the *Société des Ingénieurs civils* (*Paris*).

« At this same meeting of the 27th of Janu. 1870, one of the members of the *Institution of Mechanical Engineers*, M. H. *Hott*, acquainted the meeting that he had tried, about fifteen years previously, on the South Staffordshire railway, an attempt to transform the engine into a brake, by endeavouring to remedy the difficulties of reversing the steam, by an injection of water into the exhaust.

« At the end of eight or ten days, an accident, produced by the reversing lever getting free and suddenly flying back, which caused the breakage of the lever, and produced injuries to the engine, interrupted the experiments; which were never taken up again, even when the reversing screw was afterwards introduced in England.

« According to the details furnished by M. H. Holt, in his communication, it appears certain that the main cause of the failure was the defective position chosen on the boiler for taking the water. The cock 3/8ths of an inch in diameter, had been placed on the washing out opening in the smoke-box tube-plate, just where the ebullition tends constantly to throw down the mud and the small pieces of tartar detached from the tubes ; it is not likely that a 3/8ths cock would act regularly without being blocked up, in a similar position, and it may be admitted that it is by the want or by the insufficiency of the injection, having for consequence the heating of the cylinders, the griping of

the slides and the development of considerable strains, in the valve-motion, that the accident was brought about, which put an end to the experiments.

I mention this fact in order to complete the particulars which I have already given on a trial of injecting steam into the cylinders, made in 1858, on the *Alicante* railway, and given up in the same way in consequence of an accident.

§ IX. — Various systems.

238. Like M. *Debergue's* air-apparatus (219), counter-steam is nothing else than a brake acting on the driving wheels, by the intermedium of the pistons and the axle, not going so far as to lock the wheels. It might be thought at first sight, without going to the extent of Mr. *Tomlinson's* rejection of counter-steam, that there is a useless complication therein; that it would be simpler to act directly on these wheels, without locking them, by ordinary brakes with blocks. But the advantage of counter-steam is precisely avoiding all friction on the tires and on the rails. As to friction of the machinery, it exists always. It is even more considerable under the action of counter-steam than with the regulator closed, and a brake on; but it is so much gained for the resistance; and on the other hand, in spite of the greater pressures, the pistons and slides wear much less, lubricated with wet steam, than running without.

The means applied for slackening the driving wheels by acting on the pistons, may be varied in divers manners.

The application of the principle hitherto made use of, that is to say to employ the pistons as force-pumps, is in detail, susceptible of different variations, even leaving on one side the arrangements characterized by the fact that the piston acts in the air (245), and keeping to those in which it acts in steam.

1st. M. *Combes* proposed a modification which consisted in injecting into the exhaust, previously closed, steam taken not this time directly from the boiler, but from a space kept always at the atmospheric pressure, and at 212° F.

« In the case », said he (*), « in which it should be desirable to employ more or less frequently counter-steam, in order to moderate the velocity of trains, it would be expedient, according to us, to provide the locomotive with a closed capacity, to which should be adapted a large balanced valve, allowing the escape of the steam or air contained, whenever the internal pressure should exceed that of the atmosphere outside. This capacity would be put into communication with the lower portions of the exhaust pipes, which terminate in the blast-pipe.

(*) *Etudes sur la machine à vapeur*, page 143, *Dunod, Paris*.

« A register moved by the intermedium of a combination of levers, the setting up of which offers no difficulty, allows the driver, before putting on the counter-steam, to intercept the communication between the exhaust-pipes and the blast-pipe, and to put the exhaust openings in communication with the closed capacity, which would contain, in advance, a certain quantity of liquid water.

« This same capacity would be provided with a blow-off cock adapted to the lower part, able to be worked by the driver, or even with two gauge-cocks, if not with a gauge-glass. It could communicate with the steam-space of the boiler by a tube provided with a cock which the driver would open more or less. It might also be useful to put another small communicating pipe with a cock between the water-space of the boiler and the lower part of the condenser, in order that a certain quantity of liquid water may be brought into the latter, which would take naturally the temperature of 212°, before reversing the steam. This precaution taken, the communication would be at first intercepted by means of the register, between the exhaust orifices and the blast-pipe.

The springs of the valves being tightened so as to maintain the pressure in the boiler at the normal rate, or a little lower, and the boiler containing water up to the normal level, the driver would reverse the steam. During running, he will see that the level of the water is maintained in the boiler, and will keep the communication cock on the pipe between the steam-space and the condenser, sufficiently open to for a small quantity of steam always to pass out through the balanced valve of the latter. At the same times, the steam would pass off more abundantly through the safety-valves of the boiler, and the driver will take care to help that action by loosening the springs a little, in case he should see by the manometer an increase of pressure. Lastly, he will blow off, from time to time, the excess of water tending to accumulate in the condenser. »

The idea of the tank or condenser was suggested to him, says M. *Combes*, by the engines of the Metropolitan of *London* (136).

This closing of the blast-pipe, allowing the exit of the compressed gases, but opposing the return of the gases from the atmosphere, is without doubt a guarantee against the drawing in of the gases out of the smoke-box, which the driver does not completely avoid if he omits to open, before every thing, the steam injection tube; but the modification proposed by M. Combes, complicates both the apparatus and its working. We shall shortly see this separation of the exhaust reappear (240), a thing tried, however, long ago.

2nd. M. *Steinmetz's process.* This process, tried in 1858 (236), consisted also in reversing the valve-gear, and preventing by an injection of steam, the drawing in of the air, and its forcing into the cylinder. But this injection was made into the cylinders, employing for that purpose, the only free openings, that is to say those on which the blow-off cocks are placed. A tube, out of the heating-pipe, ended by branching off to each of the four blow-offs, which were open as well as the cock of the heater.

In a letter to M. *Bourson*, dated the 23rd of May 1870, M. *Steinmetz* states that he « has not been able to make serious experiments; it was a question only of a personal trial, undertaken without the knowledge of his superiors, » which did not allow of his making the slightest permanent alteration in the engines.

Under the conditions stated, without the injection of water, heating would not have been long in showing itself, with all its consequences.

But M. *Steinmetz* appears to have had, at any rate, one of the first, the idea of preventing returns of air by an injection of steam, and of using the blow-offs for that purpose.

Recently, Mr *Bouch*, engineer of the Stockton and Darlington (North Eastern), has applied the injection equally by means of the blow-offs, but neither the grounds for this step, nor its results seem to have been published.

A combination, pointed out by M. *Bourson*, is described in these terms by M. *Lechatelier* (*).

« M. Bourson has proposed and tried various combinations, one of which presents particular interest. It consists of injecting water into the valve-boxes, on to the slides, and to join by a tube connecting the two blow-offs the variable spaces which are separated in the cylinder by the piston. The steam admitted from the boiler during the period of forcing and of compression, passes through this communication pipe in order to fill up the exhausted volume and the blast-pipe. A moderating cock would regulate the flow from the one capacity to the other.

The relation between the two facts is not clearly seen : injection on the slides, and communication between the two extremities of the cylinder. It is a question, in fact, of two distinct things :

« With this apparatus », says M. *Bourson*, « stoppages during running would be made by means of the reverse steam with injection, without the aid of the communication ; and the latter would serve for effecting, without injection, the stoppages at the stations. »

The injection into the valve-boxes was tried on the Northern of Spain either with or without the communication between the two extremities of the cylinder, but without ascertaining any fully appreciable influence, either of the mode of injection, above or below the slides, or of the existence or absence of the communication. Of course the reason of the injection being made into the valve-boxes, in preference to the exhaust, would be the suppression of the loss of water through the chimney. But a few insufficient trials could not decide on the value of this modification.

(*) *Mémoire sur la marche à contre-vapeur*, page 135, note.

« With the apparatus for the injection of water into the valve-boxes », says again M. *Bourson* (*), « all loss of water by the exhaust is avoided ; there only comes out of the chimney steam more or less wet, which prevents the introduction of the gases into the cylinders. The quantity of water injected with this apparatus is inferior to that necessary in the primitive apparatus, and the frictions of the slides and of the pistons seems smoother with the use of this apparatus, than with that of the Northern of Spain. According to the comparative experiments made with the two arrangements, it has been shown that the expenditure of water and fuel was only a little less with the apparatus injecting water on the slides ; but to me, it is certain that the results would be much more favourable to the latter apparatus, if fresh trials were made with a cock which would permit the quantities of water to be increased or diminished. »

239. 3rd. *Running with the valve-gear reversed, and with injection, the regulator being closed.* Supposing that the driver, reversing, and injecting steam and water through the special pipe, leaves the regulator shut; the steam will thus be compressed in the induction pipe. If the regulator is the ordinary slide (109), it can, by rising against the pressure of the springs, act as a safety-valve ; the steam compressed in the closed space, attaining a pressure superior to that of the boiler and springs, will raise the slide, and will be still forced into the boiler, just as when the regulator is open. It may however happen, that the latter resists if the springs are too stiff, and in that case, either the pipe, or a valve-box will give way.

« When the valve-gear is reversed, without opening the regulator », said M. *Beugniot* in 1859 (**), the induction tubes burst, or their joints give way. Once the regulator shut, the boiler no longer acting as a reservoir, nor the safety-valves giving a passage to the air drawn in, the latter must be forced into the steam-pipe, into the valve-box, and into the induction pipe as far as the regulator-slide ; these organs offering an insufficient space, the pipes burst and the joints give way. »

It was a question of reversing, without injection, and consequently, of the effects of the compression of the air into a very limited space. With the injection, which replaces the air by steam, the danger is deferred, if not averted.

The diagram (Pl. IX, *fig.* 20) refers to an engine holding back a train on the *Etampes* incline, and of which the driver had reversed and injected water, but had omitted to reopen the regulator (***). The pressure of steam

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(*) Letter of the 10th of May 1870 to M. *Noblemaire*, director of the *Algerian lines*.

(**) *Mémoire sur une locomotive de montagne*, page 56 (Extracted from the *Bulletin de Mulhouse*, of 1859).

(***) *Mémoire sur la contre-vapeur*, page 64.

and water, confined, was far from being equal to that in the boiler. (Diagrams 21, 22, 23, were taken under the normal conditions, that is to say, the regulator being open.)

M. *Gottschalk*, engineer in chief, told me of a case of running with counter-steam, and the regulator closed (by oversight), and which caused the two valve-boxes to burst simultaneously; but perhaps the driver had forgotten the injection as well. Damage of this kind would only be inevitable with regulators which cannot yield to the pressure, for example with *bushed* regulators, or those with butterfly valves, admitting also the steam by a movement of rotation (110).

The discussion of a case in which the driver had not kept his train under command as he ought to have done, on the descent of an incline, led it to be supposed that he had perhaps omitted to reopen the regulator, which had been closed to facilitate the reversing, although it was done, not by a lever, but by a screw. M. *Villot, ingénieur des mines*, made on this subject in 1872, the following observations, on the descent with reversed gear and the regulator closed and with injection of steam and water into the exhaust :

1st. Train of about 350 tons (hauled); descent with half introduction, on gradients of one in 125, from *Aubagne* to *Marseilles*, and without whistling for the brakes.

2nd. Trains of 396 tons; descent of the same gradients without having the brakes put on. « On opening the regulator suddenly », says M. *Villot*, « a sort of slight shock was felt, as if this sudden opening of the regulator had instantaneously brought on a small increase of resistance. It seemed also that under these new conditions the train was a little more under control, but it was not very appreciable. »

3rd. Train of 380 tons; from *Valdogne* to *Aubagne* (inclines of one in 48, one in 50, and one in 67); out of the thirty-four vehicles of the train, six had their lever-brakes on; the descent was without incident, with the gear reversed right over.

At *la Bouilladisse*, the load was carried to 450 tons. Between *Pont de l'Etoile* and *Aubagne*, down one in 90, the regulator opened of itself. Closed, it opened again, and that five or six times running. It could not be kept closed as long as the back gear is right over.

Running with the valve-gear reversed, with the regulator closed and with injection into the exhaust, seems to us quite admissible, and there are sufficient motives for seeking to regulate it. It will no doubt be objected that this would be to submit to incessant causes of disturbance the only existing regulators susceptible of adapting themselves to such an operation, that is to say those which can lift from their seat, in order to allow an entrance into the boiler. It would be necessary, unquestionably, to arrange special regulators with valves, suited to these new conditions, which would not at the same time be so inefficacious, as would at first be supposed.

With suitable reverse admission, and injection, the retaining effort would without doubt reach a sufficient value in most cases, and one little below that given with the regulator open. In one of the experiments quoted farther back (225), the regulator having been closed, the mean resisting pressure was 70.40 lbs on the square inch, the mean motor pressure 10.38 lbs only and consequently the mean effective pressure 60.02 lbs (or 48 per cent of the effective pressure in the boiler), instead of 75.14 lbs, with the regulator open.

This particular way of running would no longer be, strictly speaking, *reverse steam*, which like the *motor steam* in forward gear, supposes the regulator open. But with the injection, the part of the reverse steam proper is more or less secondary, and might disappear in certain cases, not only without inconvenience, but even perhaps with advantage. Running with the regulator closed, would have the effect of making the principal cause of the local heating of the machinery disappear (217); were it only in this respect, it deserves to be studied practically.

It would constitute indeed a clearer and more logical application of the principle of sucking and forcing by the pistons, than the combination of reverse admission with injection, and the two contrary currents resulting therefrom.

240. 4th. *Closing the exhaust, in forward gear.* In this case it is a question, nominally at least, of the complete closing of the exhaust, without valve. It was introduced by M. *Zeh* on the Western of Austria, in order to moderate the velocity on the inclines; in 1863, all the engines of the *Sud Bahn* had two valves at the base of the exhaust-pipes.

The principle consists in keeping the motor action of the steam, but with a very reduced admission, opposing to it at the same time on the other face of the piston the resistance due to the prolonged compression of the steam very greatly expanded, coming from the admission during the preceding stroke.

If the valve-motion being in forward gear, and the introduction very small, the exhaust be closed, the work of the steam on the pistons changes its sign.

The work increases on the resisting face; but it is the same on the *motor* face, so that the resisting area is relatively very small. In other terms, the mean effective pressure on the pistons is only a very small fraction of the effective pressure in the boiler. The direct admission ought to be very re-

duced, for by increasing it, the motor work would increase more than the resisting work.

The following are the phases on the two faces of the piston :

Motor face A. pl. VIII, fig. 11
1st. Admission (very reduced) of the steam from the boiler.
2nd Expansion of that steam (passage of the laps).
3nd Second admission (of the steam confined in the exhaust).

Resisting face B.
1nd Forcing the steam into the exhaust.
2nd Compression of the steam, confined in the cylinder (passage of the laps).
3nd Counter-steam (from the boiler) then forcing into the latter.

The work of the pistons consists at *first* in forcing the steam, not into the boiler, but into the space limited by the stop in the blast-pipe.

But this would only be a passing effect. The forcing effected at each stroke into the exhaust, if it could be prolonged, would raise the pressure therein, equal, at the moment of closing, to that of the atmosphere; once the pressure of the valve-box reached in the exhaust, the slide could lift in order to allow the steam to pass, which would then be forced into the valve-box and into the boiler, and not into the exhaust.

In reality, it is less a question in M. *Zeh's* process, of the hermetical closing of the exhaust, than of throttling by a valve. The diagrams under these conditions, never show but a slight excess of the resisting area over the motor area.

The curve referring to the *motor* face showed an abrupt rise, in the position which corresponded in normal running to the commencement of the exhaust, and here to the second admission on to the piston; but this curve rapidly lowers afterwards, on account of the very limited initial volume of the steam which expanded.

The complete closing of the exhaust, with the pressure limited as described by a safety-valve, and without possible rise of the slide, might without doubt yield more powerful effects; but this combination would be very difficult to carry out. Under the form which it had received, this closing would finish only in fact, by profiting by the resistance proper of the engine, without encountering the drawbacks involved in running *dry*, or with regulator closed; but reverse gear, with injection into the exhaust, brings the same result (and when required, a much greater resistance) in a far preferable manner.

Let us remark in passing, that as soon as the valve is depressed, the under pressure to which the slides are subjected, allows of reversing without closing the regulator.

The following example is cited : a train of 300 tons running down an incline of one in 100, without any putting on of the brakes which had been sealed. It is quite natural that an inconsiderable mean effort may have been sufficient in such circumstances, the more so that curves of 328 yards brought in a very notable increase of mean resistance.

The *Steierdorf* engine (II, 355) was provided thus with a clack placed directly below the valves of the variable exhaust.

The closing of the exhaust had been proposed as far back as 1860(*), by Mr. Allen, an engineer.

This means was combined with an ordinary steam-brake. The closing, or rather the simple throttling of the valve, allows the steam to be let in by a special pipe, provided with a cock, into a small cylinder, the piston of which, pressed the brake-blocks on to the carrying-wheels. The cock being closed, the weight of the piston and the parts of the machinery kept the brake-blocks from contact with the wheels, but at a very short distance off.

These arrangements were tried on the Scottish Central line. The velocity of a train of 200 tons was reduced, solely by the partial closing of the valve, from 30 to 15 miles an hour on an incline of one in 83. The amount of admission was not stated. However, there is no occasion to dwell on attempts which, although said to have succeeded, were not the less given up. As to the special brake with blocks, a point to which we shall shortly refer again (264), it would be simpler to take the steam directly from the boiler instead of having recourse to the steam confined by the closing of the exhaust. It is true that the employment of steam at a very reduced pressure was looked on as a guarantee against the skidding of the wheels.

M. *Beugniot* had on his part, in 1863, applied the stop-valve to his steep gradient engines. He describes the apparatus and its mode of use, in these terms :

« These arrangements include : 1st, a stop-valve hermetically closing the steam exhaust ; 2nd, the addition to the reversing mechanism of a screw ; 3rd, a small additional slide (109, and Pl. IV, *fig.* 22) sliding on the ordinary regulator-slide ; 4th, a movement of the blow-off cocks, arranged in such a way that they can be easily opened in different degrees. This is how the running has been carried into effect and regulated. As soon as the train started slowly, and got on the incline, the driver closes the stop-valve of the exhaust, brings over the reversing lever to the notch of *forward* gear next to the dead point, opens the small slide of the regulator in such a way as to let a very sligth

(*) *Journal of the Franklin institute*, Feb. 1860. — *Newton's Journal*, year 1860.

current of steam into the valve-boxes, and opens the blow-off cocks one notch. If the regulation speed is exceeded, the driver, by means of the reversing screw, reduces the admission of steam still farther, which increases the compression. »

The closing of the exhaust is, altogether, a delicate means which can only, combined with forward gear, create a very slight resistance.

But on the contrary, by reversing the valve-gear, a useful result may be got from a valve shutting off the exhaust from the smoke-box during the aspiration, and rising during the compression. In this shape, the closing of the exhaust may be advantageously applied to running with reverse steam.

241. 5th. *Counter-steam with the exhaust closed.* It has been recently introduced on the *Dombes* and South Eastern of France lines.

Under its first form (Pl. X, *fig.* 8), the modification, pointed out by M. *Harmignies*, consisted simply in the introduction into the base of the blast-pipe of a clack-valve B nearly balanced. The drawing in of the gases, and the corresponding increase of the pressure in the boiler were thus avoided, but the heating of the piston-rods remained. Besides, on account of the manner in which it is applied, the valve obstructed the blast in the normal position, and interfered with the draught.

These disadvantages have disappeared in the apparatus as modified in the company's workshops (*figs.* 9 to 13). The clack-valve has been replaced by a register or slide D which, in normal running, is lodged in the box M and leaves the exhaust free; the driver closed it as soon as he had reversed the valve-gear. Experience has led to the application to this register, of a small clack C, pressed up by the spring F, and which allows the steam to pass out when admission of the reverse steam only takes place during 0.2 and 0.3 of the stroke of the piston.

In case the driver, going into forward gear again, should forget to open the register, the small clack C would lift and reestablish the exhaust; besides, in being thus throttled, the steam would produce a characteristic sound which would warn the driver to remedy his oversight.

In order to prevent the parts of the machinery from heating, a *cold* water pipe *p* (*figs.* 12 and 13), branches off from the pipe connecting the two tanks (tank-engines), and ends in a cock ρ placed on the blast-pipe, and which opens as soon as the register closes. These two parts are fastened together by the rod *m l* (*fig.* 13), so that the driver has only one operation to perform : the water injection can not therefore fail through oversight on his part.

The injection is manifested outside by spray coming out of the chimney,

an action which would be sufficient to render the clack C necessary; this sign is not very distinct, it is true, during dark nights, and fails altogether in the rain.

Experience has proved that it is sufficient, in order to completely prevent the heating of the cylinders, to give a diameter of 0.08 inch to the two ways of the cock.

The closing of the exhaust by a slide with clack seems to replace with advantage the injection of steam, and completes the effects of the injection of the water; it isolates with more certainty the cylinders from the objectionable atmosphere of the smoke-box, with which the communication is only established when the clack lifts on account of an excess of internal pressure. There only remains the heating to be avoided, a function perfectly fulfilled by the injection of cold water, and the notable expenditure of fuel involved by the injection of steam, is reduced or even suppressed. The spray which escapes by the chimney carries off heat, taken from the cylinders by the cold water injected; but this loss may be compensated more or less exactly, by the return into the boiler, in the shape of heat, of a portion of the work of gravity.

The trials made on the inclines of from one in 45 to one in 36 from *Bourg* to *Nantua*, and from *Mâcon* to *Paray-le-Monial*, have given good results, which a continued application will no doubt confirm.

242. 6th. *Running with reverse steam, without reversing the principal valve-gear.* M. *de Landsée* published an interesting study in 1867 (*) of an other arrangement, the object of which is to increase the mean effective counter-pressure on the pistons; a counter-pressure, which may, as we have seen, be negative, even for considerable reverse admissions (210).

The solution consists in more or less reducing the direct admission by placing at need the ordinary valve-gear near the dead point, and in opposing a reverse gear, with the closing of the exhaust. This second valve-gear is worked for each cylinder by a special slide, moved by an eccentric giving against the *forcing* piston as prolonged an admission as the *maximum* admission in ordinary motion on the piston retreating. The piston has then in this way two simultaneous admissions on its two faces, the one resistant, very great, the other motor, variable at will, and independently of the first.

The counter-steam slide T (*fig.* 15) worked by a single eccentric E (*fig.* 14),

(*) *Mémoire sur les différentes méthodes employées pour modérer la vitesse des trains sur les pentes. Landsée's system. Pamphlet,* 8vo. *Bader, Mulhouse.*

having to admit during the whole stroke almost, has no lead. It is thus keyed on at 90° to the crank, and follows it instead of preceding it, the transmission being direct, and the steam being directed *against the piston* (340).

As besides, in ordinary running, this slide ought to give no admission at all, it is worked by a link reversed *cc'* (*fig.* 14), giving like *Gooch's* link a constant lead (nothing in this case); and when the rod-pin is brought in front of the axis *c'* of the suspension of the link, the slide T is immovable in the middle of its travel, closing the two ports. Small outside laps insure this closing notwithstanding the accidental displacements of the slide, and prevent, in forward gear, leakage under its edges. It is, at the same time, kept applied to its table by the steam, which always flows into its box : which is besides one of the economical vices of the system.

The steam which fills the cylinder ought to be forced by the piston into the two valve-boxes, which communicate with each other, and thence into the boiler. Now the ordinary slide always distributing, even at the dead point, the cylinder would be in communication with the atmosphere during the exhaust period of that distribution. The blast-pipe ought then to be closed as soon as the counter-steam slide begins to act. For greater certainty, the working of the slide-pin T is connected with that of the exhaust register D by means of the lever B*b* (*fig.* 14).

The principle is ingenious; but it excludes simplicity. The apparatus has only been submitted to a few trials not followed up; we shall not therefore stop to describe all its details, which however can be easily followed out on the drawings. It will be seen that when the driver wishes to act on the pistons with full steam, he should : 1st, put the valve-gear at the dead point; 2nd, set the two counter-steam slides free to work; 3rd, close the exhaust; the forced steam returns thus into the boiler.

The two hand-wheels V, *v* (*figs.* 16 and 17) which work, the one the ordinary valve-gear, and the other the reverse gear and the stop-valve D, can be moved, either together, by putting an additional wheel A into gear with them, which would be suitable for a sudden stoppage; or separately, when it is the velocity down the inclines that has to be modified, the intensity of the resulting action being regulated by the opposition of a greater or less direct admission, to the reverse admission, always at the end of the travel. The travel of the counter-steam slide might be equally reduced, but that would have no other effect than throttling the ports.

Unquestionably superior to that of counter-steam by reversing the valve-motion, the power of the *Landsée* apparatus is not however so great as one would be induced to believe. The motor work on one face is not so reduced

as the smallness of the admission would seem to indicate, and the resisting work on the other not so considerable as would be concluded from the *theoretical* length of the reverse admission. On the one hand, the initial volume of the steam is greatly increased by the extent of the clearance spaces, so that the pressure during the expansion decreases slowly. On the other face, the resisting work is reduced by the absence of lead, and even by the drawback of the counter-steam slide: far from being subjected at the very commencement of its stroke to the full pressure of the boiler, the piston only receives the steam with a certain delay through an opening at first very much throttled, and the full pressure is not exerted on it until after a distance run through increasing with the velocity.

But what renders this system inadmissible, at least under the form given to it by M. *Landsée*, is its extreme complication.

243. 7th. *Krauss' apparatus.* The apparatus known under the name of *steam repression brake*, due to the engineers of M. *Krauss's* establishment at *Munich*, is founded on a simple and judicious idea. It consists in reversing, without interfering with the valve-gear, the direction of the circuit of the steam, arriving from the boiler to the cylinder by the blast-pipe and the central port, then driven into the boiler by the pistons.

It is sufficient to glance over the theoretical figures (Pl. X, *figs.* 18 and 19) in order to comprehend the effects produced. In ordinary running (*fig.* 18), the regulator R is open, the valve U closed, the valve V open. By closing R, opening U and closing V, connected with U (*fig.* 19), the current of steam is reversed; nothing is changed in the relative positions of the slide and the piston (for the same notch, the same drawing applies thus in both cases); but the parts of the two faces AB of the piston are inverted, and at the same time, the atmosphere is replaced by the steam which fills the space limited by the closing of the regulator.

Figures 20 to 24 give a sufficient idea of the mode of applying the principle.

The valve-motion should, if the state of the rails allows, be in full forward gear, and the maximum admission, from direct (face A, *fig.* 18) becomes reverse (face B, *fig.* 19). The compression which follows on the reverse admission, only then corresponding to a small fraction of the stroke of the piston, and exerting itself besides, on steam coming from the boiler, and consequently very wet, the latter cannot be superheated by that slight reduction of its volume.

At the moment when the slide, uncovering the port *l'* (*fig.* 19), establishes the communication between this steam at a higher pressure than in the boiler and that which fills the valve-box, a certain local heating is pro-

duced, but much less than with counter-steam by reversing the valve-motion.

The phases, three in number on each of the faces, are:

Motor face A.	1st admission of the steam, confined within the valve-box. 2nd Expansion of the steam, confined in the cylinder. 3nd Communication with the exhaust, that is to say with the boiler; 2nd admission
Resisting face B.	1st Counter-steam (steam coming from the boiler) and forcing into the latter. 2nd Compression of the steam, confined in the cylinder, 3nd Counter-steam (steam coming from the valve-box) and forcing into that box.

The work of the piston consists, as with the valve-gear reversed, of forcing the steam into the boiler; but that steam acts with full pressure at the very commencement of the stroke.

The distribution being at the full travel of the slide, the piston is subjected during the greater part of its stroke: on one side (B), to the pressure of the boiler (exhaust period in ordinary gear); on the other (A), to the pressure in the valve-box (period of admission in ordinary gear).

It is thus desirable that this pressure should be as slight as possible.

At the outset, at the moment when the driver closes the regulator R, this space is filled with steam at the pressure of the boiler.

From that moment, the box, completely isolated by the slide from the exhaust, that is to say from the boiler, contains, if there is no leak, a constant quantity of steam, yielding to the cylinder, at each stroke of the piston on one side during admission, a quantity equal to that which it receives on the other side, by the forcing of the steam. The slide floats in this mass of steam, the heat of which is maintained by that which the steam from the boiler brings to the metal surfaces it is in contact with.

During admission (1st, A) the pressure in the box constantly diminishes. It has its *minimum* value at the moment when the expansion commences in the cylinder alone (2nd, A) and keeps it up to the moment when the forcing into the valve-box is effected (3rd, B), that is to say, very nearly to the end of the stroke of the piston. It then rapidly increases and reaches its *maximum* value, which depends, for a given pressure in the boiler on constructive details (volume of the box and of the induction pipe, clearance, amount of lap). It may happen that this maximum reaches and exceeds the pressure in the boiler, but it corresponds to a very small travel of the piston (then almost at the end of its stroke), and consequently to a very small amount of motor work; and the piston, changing almost immediately its direction, sucks in that steam, the pressure of which rapidly lowers.

Fig. 23 represents an appendage of the supply pipe, provided with a valve

nearly balanced, and with a cock. The valve X as for the object of preventing the pressure in the box rising above the atmospheric pressure; a precaution which would be almost always useless, this very limited rise having only, for the reason just stated, a very slight influence on the final work of the piston. The cock K serves, at will, to check the action of the valve, the lifting of which would involve a loss of steam without real gain for the effect in view, the increase of the mean retarding force.

The addition of these two organs is, so to say, the expression of the uncertainty which exists respecting the nature of the effects produced. They have not been sufficiently studied by the application of the indicator.

M. *Linde* (*) seeks to establish that, with a reverse admission of 0.92 (which exceeds the possible limit in most existing engines, in which the maximum exhaust does no reach that figure), the pressure in the confined space in question is comprised between $\frac{1}{8}$ and $\frac{1}{2}$ of the pressure in the boiler, conditions under which the motor work (face A) is scarcely more than $\frac{1}{5}$ of the resisting work (face B); but to support these considerations there are neither experiments nor diagrams.

It is really singular that this mode, assuredly the most rational of applying counter-steam to the destruction or moderation of speed, should have been so little studied. Its authors themselves seemed to have lost confidence in its principle, and neglected to record its advantages, and to overcome the imperfections of a primary trial.

The slides, subjected internally to the pressure of the boiler (and on one hand to a much greater pressure during the period of expansion), pressed externally by the generally rarefied atmosphere of the valve-box, ought to be kept applied against the face. Such is the object of the piston π (*fig.* 24), let into the steam-chest and pressed on to the slide by the pressure of the boiler transmitted to it through the tube τ, communicating with the exhaust-pipe, which has become the admission pipe.

On inclines of average steepness, whereon the mean effective effort may be reduced, it is not, as would seem natural at first sight, by a diminution of of the admission in the contrary direction, that the reduction of the effort is effected. The period of compression, and consequently of the calorific effects of the period which follows (introduction of the compressed steam into the valve-box), or else the loss of steam would have arisen. The gear (as in the Landsée brake and on the same grounds) remains then at the maximum of

(*) *Ueber einige Methoden zum Bremsen der Locomotiven, insbesondere über die Dampfrepressionsbremse.* München, 1868.

travel of the slide, and it is the pressure of admission of the motor-steam which varies. The work regulates itself by opposing, to this resisting work nearly invariable, a motor work, variable at will. The steam is thus designedly (as takes place more or less necessarily, in forward gear in valve-motions, with a single slide) opposed to itself. It is thus on the regulator R that the driver acts. He opens it more or less and shuts it, in such a manner as to maintain in mean, the desired velocity.

This method is not satisfactory. It is irksome to the driver; it does not constitute, it is true, as in forward gear, an inefficient mode of employing the steam; but if counter-steam by reversing the valve-motion has less power, it is more manageable.

Altogether, the brake in question is ingenious, it involves no expenditure of steam; it returns wholly to the boiler, carrying it back in the shape of heat, a great portion of the calorific equivalent of the work expended on it by the pistons. But we have already said: in the descent of long and steep gradients, it is necessary that the equivalent of the excess of the work of gravity should be lost as soon as the limit of the boiler pressure is reached, and the escape is then effected by the valves, which ought even to be unscrewed. All that can be done is not to expend fuel perceptibly (224).

The *Krauss* brake, although known for some years, has not yet come into use. Tried on several lines, among others on that from *Saarbrück* to *Trèves*, and on the Bavarian State lines, it has been given up, although its superiority over the counter-steam, by reversing, in what regards the power of effect, has, it is stated, been fully ascertained. Its complication is complained of; to this objection, which it is far from being merited in the same degree as *Landsée's* system, ought also to be added probably that of a somewhat inconvenient manner of working.

244. *Necessity of further investigations into the various modes of application of counter-steam.* In substance, notwithstanding the merit of the conceptions of M. Landsée and M. Krauss, the old reversing of the valve-gear, completed by two improvements the one already old, the reversing screw, the other more recent, the injection of steam and water (or of water only, which is only a particular case of it), is still the only practical means of utilizing the machinery of the engine for obtaining without destructive friction, the stoppage of trains or the checking of their velocity down inclines.

What precedes shows at the same time that many points still remain to be studied in order to obtain the greatest advantage possible out of the elements which the engine, with the action of steam, presents as a means of stopping,

and in order to reduce the expenditure resulting from an action which ought theoretically to be gratuitous, if not even productive of work. Among these are chiefly the closing of the exhaust, the use of cold water, the mode of injection, above or below the slides, and running with closed regulator, including the study of an appropriate form for that organ. Let us add, as an important desideratum, a profound discussion of the different types of valve-motion, from the point of view of reversing: a question which we have not been able to treat with the necessary developments, and by enlarging upon observations sufficiently numerous.

§ X. — Remarks on apparatus founded on the same principle as counter-steam.

245. 1st. *Use of air.* M. Debergue's air-brake, tried in 1865, on the Western of France (*Saint-Germains* incline of one in 29), was founded on the same mode of action as counter-steam, that is to say, by turning the cylinders and pistons into force pumps. Only, in order to escape the disadvantages of the impurity of the hot gases drawn into the smoke-box, and forced thence into the boiler, M. Debergue replaced the first by the atmosphere, the second by a receptacle into which the air was drawn. He injected steam into the cylinders, but only with the view of preventing the griping of the pistons.

This was hardly sufficient even on inclines of limited length, such as those of *Saint-Germains* and *Montmorency*. According to M. de Forbonne (*) temperatures were recorded on the second (1312 yards on one in 22) of 266° in the receptacle and from 410° to 430° in the valve-box. So far there is nothing excessive ; a longer continued action would have required an injection of water. But under this form, the substitution of air for steam involved a notable complication and without any compensation.

Thus counter-steam has replaced compressed air. A ministerial order prescribes a brake for three vehicles; further, the engine is behind on the ascent. The conductor of the train, always in the front, and partly taking the driver's place, orders the brakes to be put on by blowing a horn.

On week-days, two large two-storied carriages, on *Vidard's* system (II, 40), with 86 places, are sufficient. On Sundays and holidays, the extra is formed of Northern of France carriages, with Newall's brake, the counter-weight of which is set free by the conductor or the driver.

The use of air, to the exclusion of steam, has been, as we have seen (II, 437), realized more simply by M. Riggenbach, who takes air in from the

(*) *Mémoires de la Société des ingénieurs civils.*

atmosphere, and restores it by forcing it to pass through, in order to get back, a contracted opening, regulated as required.

2nd. *Use of a liquid.* In order to obtain a great amount of resistance by the compression of the air taken at the pressure of the atmosphere, a large initial volume must be operated on, that is to say with large cylinders. This condition leads naturally, in certain cases, to the idea of replacing the air by liquids. The objection is the fear of breakage, a danger which may be got rid of by the low speed, and consequently very short stroke of the special piston, and by the mode of working the cock regulating the contraction to pass through. Locomotives are, at least up to the present time, disinterested in the question. Having large cylinders, they utilize the steam for resistance as well as for power. But as it is always instructive to group together the divers modes of application of the same principle, we shall say a word here on the use of liquids, that is to say of water.

An example is found, not a very extended one it is true, of the principle, in the hydraulic regulator applied by *Boyden* in 1844 to the lever of *Prony's* brake, in order to get rid of the impulses and shocks which often put out the working of that apparatus. This lever is connected (Pl. XI, *fig.* 1) to the vertical rod of a piston P, plunged in the water, and which, on account of the incompressibility of the liquid, can only rise or fall by making water pass from one face to the other by the annular space, *j*, *j*. The movement of the piston, and consequently of the lever, thus greatly slackened, gives time to modify more or less the tension of the brake-screws, before the lever has undergone any notable displacement. Among the innumerable projects for brakes submitted to the Public Works Department (France), there is one dating back to 1859, and which is described in the following terms in a report addressed to the brake commission in 1863 (*):

« M. *Gros-Renaud* proposes an hydraulic means of action on the axles which would carry a loose eccentric, able to be fixed at will, the rod of which would work a piston in a pump, the extremities of which would be in communication with each other, the communication being regulated by a cock. When the wheels are to be acted on, it is only necessary to fix the eccentrics, and turn the cock. The communication must never be completely closed, or the whole thing would be smashed; but it would be easy so to arrange matters. In winter, to prevent freezing, spirits of wine would have to be added to the water. »

But the same principle had been pointed out, as far back as 1855, by

(*) *Rapport de M. Bochet,* ingénieur des mines. Pamphlet 4to, page 20.

M. *Le Bleu*, ingénieur des mines, in a note addressed by him to me at that time, and which I kept in a selection made from numerous communications relative to rolling stock and working. It is fair to bring forward this short note here, as it clearly establishes the essential feature of the proposed brake, that is to say the indefinite circulation of the same mass of water forced from one compartment of the cylinder to the other through a contraction regulated at will:

Description of an electro-hydraulic brake for railways.

« This brake should be adapted to every vehicle in a train.

« Each of the two axles of a carriage is provided with an eccentric. The two eccentrics give a reciprocating movement to a rod which connects them at each turn of the wheel. This rod drives, by means of a slot, a piston working in a bored cylinder full of water, the front and hinder portions of which communicate by a tube of large diameter. In this tube is a cock which controls the passage of the water, and cutting off the water altogether when required. The velocity of rotation thus depends on the opening of the cock. Now this opening can, without difficulty, be obtained by means of a spring with its escapement regulated by an electric current.

« It is then sufficient, in order to establish the electro-hydraulic brake, to adapt to each waggon a cylinder the piston of which is driven by eccentrics, and to regulate the cock placed on the communication between the front and hinder portions of the cylinder by means of an electric current interrupted at will.

« By this means, the conductor, the driver, or any other official, can regulate the speed of the train, by moving an index.

Rive de Gier, December the 21st 1855.

Save the application to several vehicles, and the regulation of the cocks by a current, the principle enunciated by M. *Le Bleu* is precisely that which has been recently applied, as extra guarantee, to the locomotors constructed by M. *Agudio* for the inclines reaching one in 26, at *la Ramasse* (II, 463 to 467). We shall return farther on to this addition (288).

As regards locomotives, the length of stroke of their pistons does not permit of the use of water as a brake for them, which would also offer other very serious difficulties; and to apply special cylinders to them, could hardly be thought of. The best thing is to continue to use the steam, or perhaps the air taken directly from, and forced back into the atmosphere.

In a note inserted in the « Bulletin des anciens élèves des écoles d'arts et métiers », M. *Larpent* proposed to introduce into the cylinders, after reversing the valve-gear, not the steam, but the water from the boiler; the ordinary regulator would then be closed and replaced by a water regulator, placed below the level of the roof of the friction. But M. *Larpent's* proposition is made in too summary a way to be usefully discussed.

CHAPTER III.

ENGINE BRAKES UNCONNECTED WITH THE MACHINERY

§ I. — Steam-brakes

246. *Utility of a brake applied to the engine itself, independently of the tender-brake.* The tender-brake is obligatory, as it should be; this vehicle is heavy (although its weight varies with the consumption of water) and at the very hand of the driver, which insures both its power and its prompt action. These same grounds are applicable, and indeed *a fortiori* to the engine itself. We thus consider that it also should always be provided with a brake proper. Counter-steam renders this in no way superfluous; as it may be paralyzed from various causes and particularly by the breakage of a tube, an accident frequent enough, and which may be brought about by the very use of counter-steam, if the precautions necessary against the rise of pressure, are not duly taken.

In any case, the application of a brake to the engine itself is neither obligatory, nor very frequent, unless of course, in the case of tank-engines, in which it replaces, ordinarily with more power, the regulation-brake.

Like carriage-brakes, those of engines are founded on the old principle of the brakes of ordinary carriages. The resisting force is obtained by developing pressures, and consequently friction between pieces animated with relative movements (201).

According as the pressure is applied to the rim of the wheel or to the rail, it is the first or the second which undergoes sliding friction. At the limit, that is to say when the wheel skids, the position is the same, the sliding being brought in both cases, on to the rail; but this sliding, very detrimental for the tires and for the rails, appears to be also injurious as regards the retarding force (248).

The idea was long since entertained, for engines which had to be provided with a friction-brake, to make use of the steam from the boiler, to insure its prompt action. At first sight this seemed even preferable to counter-

steam, to which was objected, independently of the drawbacks since remedied (219), that it uselessly involved the whole of the machinery in the stoppage of the wheels.

Was it not much simpler to act directly on these latter? Was it not at the same time much more economical, seeing that it was sufficient for the production of the resisting force, to keep the blocks more or less tightened against the wheels, which only involves an insignificant quantity of steam, while counter-steam constantly expends it, and in notable quantity (224)?

But looking closer into the matter, it is found that counter-steam is altogether, and precisely from the point of view of the preservation of the engine, preferable to steam pressing the blocks against the tires of the wheels. Thus in recommending the application of an ordinary brake, to all engines, as a most useful guarantee (independently of the tender-brake), let us exclude the brake worked by steam; the best of the brakes of that kind, is, in principle, and the word being taken a general sense, counter-steam; and the ordinary brake ought to have for special function to supplement the latter, in case of the breakage of a tube, or for any accident to the boiler. It ought thus essentially to be independent of conditions of pressure, that is to say, worked by hand.

The only argument of any value in favour of the ordinary brake, is that it acts, if desired, on the simple carrying-wheels, while counter-steam acts only on the driving-wheels; so that by combining the two means, the steam can be employed to stop all the wheels of an engine with partial adherence just as counter-steam does alone in engines with all the wheels coupled. But an ordinary brake seems always necessary on the grounds just now pointed out, whatever may be the number of wheels coupled; and in engines which have wheels simply carrying, it is desirable to apply the brake by preference to these latter, unless their load be too small.

In engines with all the weight adherent, and which are like tank-engines provided with a brake with blocks, the latter acts often only on a single pair; but, as all the wheels are solidly connected by the coupling-rods, there are in reality two distinct means of acting on them : counter-steam, and the hand-brake, which, I repeat, do not make a double use.

The second ought, in general, only to be employed, when the first fails, or when the driver, for a more or less valid reason, does not think proper to make use of it. There is scarcely but one case in which it is desirable to work them simultaneously : that in which the driver, nearly at the end of his journey, having let down his pressure, the diminished action of the counter-steam should be made up by that of the brake.

To the objections presented just now, against the brake with blocks worked by steam, comes another, without doubt little founded in principle, although it arises out of the practice of certain lines. The tank-engines which work the *Auteuil* line had steam-brakes put on to them, which seemed appropriate to that small line, with frequent stations; they have been given up, because their action appeared too abrupt. It is the same as regards the brakes applied to some of the *Crampton* engines on the Northern of France, which entered long since, resolutely, on the application of ordinary brakes to locomotives. Those in question have been replaced by hand-brakes.

What is complained of with respect to the first is in reality a good quality in urgent cases; and if, for ordinary service, the action is too instantaneous, it should not be difficult to remedy that by the mode of admitting the steam.

Figures 27 and 28, Pl. IX, give a sufficient idea of a type of steam-brake, some examples of which are found in Germany, M. *Hartmann's* of *Chemnitz* (Saxony). The tube which brings the steam under the piston P, carries a cock which serves to establish the communication between the bottom of the single action cylinder, either with the boiler for putting the brakes on, or with the atmosphere for letting them go. On each side of the engine, the lever L, suspended from the longitudinal, presses the blocks S, S, jointed on the ends of the beam T, on the top of the wheels.

To the *Steierdorf* engine (II, 555) was put, besides the exhaust-valve (240), a steam-brake with blocks applied to the tops of the 2nd and 3rd pairs of wheels (Pl. XI, *fig.* 2). Two vertical pistons act independently, the one on the right hand wheels, the other on the left hand ones. The jointed cross-beams T insure the equal distribution of the pressure, between the blocks s, s' whatever may be the difference of level between the two wheels. By letting free the steam which raised the pistons, the weight of the parts immediately takes off the blocks.

The blocks thus applied at the vertical diameter of the wheels, bringing thereon a great portion of the load of the journals, diminishes instead of increasing their strain; but on the other hand, they paralyze the action of the suspension springs, and thus enhance the rigidity of the reactions, and the fatigue of the permanent way. Altogether, they are little in use.

Steam has been equally applied to working of skids acting directly on the rails; but chiefly with the view of reducing the velocity down steep inclines. Such is the case as regards the engines working the line from *Leipsic* to *Hof* (Saxo-Bavarian).

The piston P brings on to the skids p, p, a portion of the suspended weight, equal to the pressure on the piston multiplied by the ratio $\frac{om}{on}$ (*fig.* 8).

This brake, according to its partisans, escapes the objection often made to hand-brakes acting directly on the rails; the steam forming a spring, does away, they say, with the shocks which are produced particularly at crossings and points. If the objection is diminished, it remains however to such an extent, that the working of brakes of this kind in stations, is now prohibited in Saxony. A brake which cannot be made use of in stations, is evidently a very imperfect apparatus.

We shall not dwell further, on the ground arrived at before, on steam-brakes to which hand-brakes, very simple seem preferable.

§ II. — **Hand-brakes.**

247. *General conditions which they ought to fulfil.* Before running our eye over this class of brakes, let us recall in a few words the conditions which the mechanism of the transmission of the effort to the blocks should fulfil; conditions common to all vehicles, but of unequal importance, and which are in part sacrificed when simplicity is insisted on, either, as in certain categories of carriages, from economy, or, as in engines from want of room, which does not allow the parts to be multiplied.

1st. At rest, the blocks ought to be maintained as close as possible to the tires, without however touching them (ordinarily 0.39 inch at most), and the mechanism of transmission should be arranged in such a manner as to bring them rapidly into contact. It is necessary therefore to exert on the primary organ, at first a slight effort with great velocity, then the contact once established, and the block thence immovable, an effort rapidly increasing and with a low speed, the distance only having the flexion of the parts to make up.

Various special arrangements (springs, double screw, counterpoise) may be made with respect to these two distinct periods : the putting on of the blocks, and the tightening up. But as these involve a certain complication, they are hardly ever applied to engines, at least to engines with separated tender. The rapidity of the approach of the blocks depends thus on the velocity imparted by the man, up to the moment of contact, to the organ, screw, or lever, on which he directly acts.

2nd. A pair of wheels once skidded, any further tightening only strains

the parts for nothing. It ought not to go so far as complete skidding, which does not correspond to the maximum of the retarding force (248), and which would produce flat places on the tires, intolerable especially for engines, on account of the violent shocks involved thereby. The wheels ought to be almost in equilibrium, still turning round, but on the point of stopping. If the equality of the coefficients of the friction of the tires on the rails and on the blocks be admitted, the pressure exerted on the latter should be a little below the load of the wheels on the rails.

3rd. The total effort exerted on all the blocks tightened up, ought to be distributed over them very nearly as the loads brought on to the rails by the wheels to which they are applied, and that, as much as possible, in spite of the unequal wear of these blocks.

With certain mechanisms, if some of the blocks screwed up hard, wear quicker than others, they escape the pressure, which may even be concentrated on a single one. The remedy, it is true, arises up to a certain point from the evil itself, provided the wheels are not skidded; the blocks to which the sliding friction is brought, wear in their turn, and catch up the others. But the same effects recommence, and the position, which should be normal, is purely transitory.

4th. If, from the point of view of the effort of the brake, one single block is sufficient for one pair of wheels, it is desirable however in general, to avoid that arrangement which only acts on the conjugate wheel by subjecting the axle to torsion, and especially by tending to unkey (II, 319) that wheel.

5th. The pressure of the blocks, ordinarily placed in the line of the centres, is taken by the horn-plates and the journals, on to which it brings an extra strain; this can be avoided by acting on each wheel by two blocks diametrally opposed : a complicated arrangement, but frequent however, especially in Germany.

6th. There are thus ordinarily, on each side of the vehicle, at least as many blocks as there are wheels to be acted on. But this rule is scarcely applicable to engines with coupled wheels, usually very close together, in which it would be difficult to find a place for the intermediate blocks and the mechanism for working them.

Advantage must then be taken of the connection between those wheels by means of the coupling-rods, and instead of spreading the pressure over them by blocks, it must be concentrated on two pairs, or even on a single one, generally the hinder pair. These coupling-rods are thus, under the action of the brakes, those which undergo the greatest strain, and unless

the pair of wheels to which the blocks are applied are the driving ones, this strain is greater than that to which these rods are subjected when the engine is at work. In this respect, it is preferable to apply the blocks to the driving pair, ordinarily the intermediate one, which spreads then on both sides by the coupling-rods, as takes place for the motive power, the pressure whence results the retarding force. When this is not the case, the extra strain which may be brought on to the hinder coupling-rods by the action of the brake, must be taken into account in determining the dimensions of these rods (197). It is so for example, in the engine with eight wheels coupled, constructed by the firm of Kœchlin for the Ceinture railway (*Paris*) (II, Pl. LV). In the engine with ten wheels coupled of the *Orleans* lines, with blocks applied equally to the hinder pair, the dimensions of the rods were fixed without attending to this consideration (II, Pl. LVIII).

7th. The tightening of the brakes ought, as much as possible, to leave the bearing springs free to effect their oscillations.

From this point of view, the brakes with blocks in the line of centres go into two classes : 1. those the blocks of which are hung from the frame; 2. those, the blocks of which are directly supported by the axle-boxes (brakes with struts). When the first are tightened up, the wheel taken by the block becomes thus consolidated with the frame, which paralyzes the suspension more or less completely. With the second, the freedom of the springs remains intact.

The suspension of the blocks has another drawback. The level of the frame varying with the load, it is the same with the position of the blocks relatively to the wheels, on which they become imperfectly applied.

248. *Skidding the wheels. Disadvantage of prolonged skidding, from the point of view of the resistance.* Let us stop at this principle laid down just now, that the pressure of the blocks ought to approach that which would produce skidding, but should not reach it.

It is evident that prolonged skidding ought to be avoided. It brings into play most objectionable conditions, both for the tires, on which flat places are formed, far more injurious than uniform wear, and for the rails. It is far preferable to allow the wheels to turn, although they wear, they remain round, and to replace the wear of the rails, by that of the blocks.

But it is generally admitted that skidding ought to be avoided also from the point of view of the resistance offered by the brake. If opinions vary as to the relative values of the resistance obtained on each side of the skidding point, almost every one attributes a very marked influence to

that circumstance. According to observations made by M. *Wöhler* (*) on the Lower Silesia and the Mark railway, the resistance before skidding falls immediately afterwards to 1/2. Such an intensity and promptitude of action would not be easy to explain.

We have no intention whatever of contesting the correctness of the observations, upon which the widely spread opinion is founded, of the less resistance opposed, at least at the end of a certain time, by skidded wheels; but perhaps these observations have not been multiplied enough. A quite recent trial, made in England, on the subject of comparative experiments on different systems of brakes (287), would tend to establish, contrary to the law in question, that wheels decidedly skidded have a very superior action to that of wheels which are only on the point of being so:

« A train composed of six brake-vans, all with brakes fitted, was drawn by an engine which imparted a determined speed to it on a horizontal, and was then uncoupled by a catch, and ran on in front. At a given signal, the six guards screwed up the brakes as fast as possible : in a first experiment, keeping a little below skidding, and in a second, skidding; the two distances run being measured, these distances brought to the same nitial velocity (50 miles an hour), were.

Without skidding, 449 yards; with skiddng, 316 yards : or 30 °/. less.

And it should be added that one of the vans, with cast-iron blocks, could not be skidded.

This experiment is doubtless not perfectly conclusive. Perhaps the guards, being too anxious to attend to their orders not to skid the wheels in the first case, did not screw up tight enough. But what can at least be concluded in the matter is that new experiments are necessary, and that the law in question is neither so constant, nor so general as it is asserted to be.

It is clear at the same time that if it is generally exact (which is probable, the facts which confirm it being much more numerous than the contrary observations), it is clear that it is only on account of the influence exerted by the skidding on the value of the coefficient of friction. If the coefficient did not vary, it is evident that an increase of the pressure applied to the block could not have the effect of reducing the resistance opposed by the wheel. As long as the moment of the friction on the block is less than the moment of the friction on the rail, that is to say so long as the first friction is less than the second, the wheel turns; and the resistance

(*) Zeitschrift für Bauwesen for 1867.

is $fp < f'P$, f and f' being the coefficients of the friction of the tire on the block and on the rail, p the pressure on the first, P the load on the second. When p reaches and exceeds the value $\frac{f'P}{f}$, the wheel is skidded, an the resistance attains its maximum value : $f'P$.

It is quite true, that this value may decrease afterwards, if the skidding be prolonged; the surface of contact, at first very small, increases rapidly; a flat place forms; the coefficient f' diminishes by that very fact, and it may diminish also, independently of the direct influence of the extent of surface, in consequence of the polish taken by the flat place.

A very judicious practice consists, not in prohibiting skidding, but in preventing its being continued long enough for flat places to form; thus both the deformation of the tires and the diminution of the coefficient f', and consequently of the resistance, which is the consequence of the formation of the *flat places*. It was in this way the brakesmen on the Mont-Cenis temporary line proceeded, on inclines of one in 12.5 (II, 424), but at the cost of continual and laborious exertion.

An argument was thought to be found in favour of this successive and closely repeated skidding and unskidding, beyond the prevention of flat places. It is supposed that by letting the wheels take again, by unscrewing, a velocity of rotation which screwing up rapidly destroys, the *vis viva* of the train is abstracted, so to say, in small doses. But it is evident that if the coefficient f' always kept at the maximum value which corresponds to the beginning of skidding, there would be nothing better to do, from the point of view of resistance, than to leave matters in that state; only rotation at least intermittent being indispensable for avoiding flat places, the pressure on the blocks may be usefully pushed, during the period of the destruction of the rotation of the wheels, beyond the limits of statical skidding; so that the alternatives of excess and want of pressure, are very nearly equivalent, as resistance, to permanent skidding.

249. Let us return specially to engine hand-brakes, and let us rapidly enumerate the examples given in the atlas of vol. II:

Pls. XLIII and XLV. Tank-engines with six wheels coupled of the Western of France ; driving-wheels behind. The shoes s, s' are applied to those wheels.

Pls. XLVI and XLVII. Tank-engine with six wheels coupled of the *Creuzot;* driving-wheels in the centre. The brake acts on the hind wheels, but by taking each of them by two opposite blocks s, s. The shaft worked by the screw acts on the hind blocks by means of rods applied at their middles, and on the front blocks by the rods β, γ, jointed on the extremity γ of the suspension rods γ, δ. The two cranks are keyed on each side of the brake shaft at 180° to each other. This shaft is in rotation equilibrium, under the

action of the three moments of the tension of the screw, which influences it in one direction, and of the moments of the block-rods which influence it in a contrary direction. The ratio of the cranks of the shaft, and that of the distances γ and δ of the suspension-rod of the hind block, are determined in such a manner as to give on the opposite blocks nearly equal pressures.

Pls. LV to LVII. Engines with eight wheels coupled by *Kœchlin;* the driving-axle is the third; a single block on each of the hind wheels. The driving-screw has a low pitch on account of the considerable pressure necessary to nearly scotch the eight wheels. Holes made in the continuation of the rod allow the wear of the block to be taken up.

Pls. LVIII and LIX. *Orleans* ten wheels coupled engine. Same arrangement.

Pls. LXI and LXII. Old engine with twelve wheels coupled; (now altered (10)) of the Northern of France; to each of the groups of six wheels, and between them, a pair of blocks *s*, *s* was applied. On account of the small space between the wheels, one of the blocks was placed a little above the other, and a little below the line of centres, on which the working-shaft was, the cranks of which acted on the blocks by means of claws which were partly over each other.

Pls. LXIII and LXIV. *Vaëssen's* engine with six wheels coupled; driving-wheels in front; blocks applied to the hind wheels.

Pls. LXV to LXVIII. Another *Vaëssen* type, with driving-wheels in the middle. The middle and hind wheels not being so close as in the preceding engines, the block is placed between them, on the driving-wheel.

Pls. LXXI and LXXII. Old *Seraing* engine. One only of the groups of wheels is furnished with brakes. Each of the four wheels is taken on both sides by the blocks *v*, *v*. The crank is placed on the fireman's side that is to say on the opposite side to that shown in the elevation.

It is sufficient to glance over the plate to see how the fireman acts on the blocks through the intermedium of the crank ε, of the rod ξ, of the endless screw and of the toothed segment η, of the connecting-rod *i*, of the shaft λ, and of the connecting-rods ν, μ acting, the long ones in extension, and the short ones by compression.

Pl. LXXVII. *Engerth* engine proper, that is to say, with articulated truck encompassing the fire-box (figs. 1 and 2); the brake acts on the last axle of the articulated truck. With the gear-work (figs. 3 and 4), the coupling-rods transmitted the action of the brakes, like the movement of rotation, to the other axles of the same group, and the gear-work transmitted it to the first group. But this function was a very serious cause of destruction to the gearing, impossible besides, even for traction.

Figs. 1 to 6, Pl. XII, give with the figured lengths, the outlines of six engine-brakes applied on the Western of France.

Altogether, brakes with blocks applied to engines, even to tank-engines, are generally simple, and only incompletely fulfil the whole of the conditions, more or less essential at the same time, to which carrying stock is more readily adapted. There is no hesitation in transmitting the action of the brakes by the intermedium of connecting-rods; and experience proves there to be no drawback in so doing. It is chiefly slipping in running with steam, direct or reverse, which causes the breakages of rods; the velo-

city of rotation becomes accelerated with extreme rapidity, and should the driver delay closing the regulator, it reaches an enormons value. The danger of the breakage of rods is thus imminent, even with the most perfect fitting of the cranks, as the force of inertia may attain and exceed the limit of resistance of the rods.

Simplicity, from which builders in general take care not to depart in the application of hand-brakes to engines, is sometimes sacrificed. Some examples of this were seen at the Vienna Exhibition in 1873 (engine of the Bavarian State railway, constructed by J. A. *Maffie*; engine of the Russian lines, etc.). The principle of the apparatus which bears the name of *Heberlein* in Germany, has been long known and has been tried under different forms, in different places, particularly in France, where it was applied to waggons of the Orleans system under the name of the *Noseda* brake, or the *curé's* brake (Pl. XI, *fig.* 4).

The parent idea is to take from the *vis viva* of rotation of one of the pairs of wheels, the work necessary for screwing up the brake. This is in a few words how it is carried out in engines (Pl. IX, *fig.* 24).

The two cross-beams of the frame, between which the acting axle is comprised, support two longitudinal beams very close together; the latter serve as supports to the axis of rotation of a frame formed of two curved webs *f*, *f'*, bearing at their free extremities a counterpoise P, and at A the bearings of a roller, *g*. At rest, the lever is held up in the air by a rod with a bolt, ending on the foot-plate; as soon as the driver undoes this bolt, the roller *g* presses against a similar roller G, keyed on to the middle of the axle, which carries on the first in its movement of rotation; on the axle of the latter is wound a *Galle's* chain, which works the lever of the brake. The movable counterpoise P allows the pressure to be regulated between the two friction rollers, in such a way as not to reach the skidding of the wheels.

Figures 25 and 26 give the diagram of the brake of this kind applied to engines constructed by the *Berlin* Company. The chain *k m* transmits, by the bent lever *m n p*, the tension of the draw-rod *g* (*fig.* 26), then, by means of the levers *o i*, *o i'*, to the rods *l*, *l'*, and to the blocks S, S.

A system which is already, and long has been found too complicated for waggons, is scarcely in its place on the locomotive. It is essential, before every thing, that an engine brake should be simple, of certain effect, and that it should not bring in, with multiplied organs, new causes of getting out of order, and going into the sheds.

If simple arrangements are departed from, if new organs are admitted into

the engine, it should be by taking up another order of ideas, and proposing, as in the *Westinghouse* brake for example, on which we shall say a few words farther on (283), to make the engine the starting point of the means of stoppage, acting on the whole length of the train by suitable means of transmission. Until this difficult problem be solved, counter-steam, and a very simple hand-brake, applied to the engine proper, and utilizing either the whole, or even only a part of its weight, appear to us to give sufficient guarantees for safety, without rushing into suspicious complications, both from the point of view of economy, and from that of the *efficacy* even of the apparatus.

250. *Hand-brake with skids.* Pl. XX, II, *fig.* 2 (*Couillet's* engine) offers an example of this application. A strong cross-beam ε fixed on each side to the hind guard-plates and to the frame, guides the skid, and brings the load on to it at will; the screw wheel, the cranked lever α β γ, and the spindle γ δ act on a knee, the upper end of which is jointed at ε on to the cross-beam, and the lower end of which presses on the skid.

The general centre of gravity is at the middle of the distance between centres, and the brake, as it is arranged, can carry the two thirds of the suspended weight. The distribution which is, when the brake is not in action :

Leading axles.....	11,298	22,833 tons
Trailing do.....	11,535	

becomes when the skids have their maximum load:

Leading axles.....	7,593	22,833 tons
Trailing do.....	15,240	

The pair of hind wheels is thus slightly uplifted. The stability of the engine is not compromised, on account of the sufficient load of the leading axle, and of the flanges with which the skids are provided.

The very frequent action of brakes and the fear of wearing the tires are the arguments invoked in favour of this arrangement. Nothing better than to think of the tires. But the rails?

A brake with blocks on the wheels would be on the same time more powerful (because in this case a third of the weight is lost) and altogether more economical, on condition of avoiding the skidding of the wheels. It is only for very long continuous distances on brakes that the question would perhaps change its aspect, the blocks in that case being likely to alter

the temper of the steel tires so much in vogue now, not however without reason, and take fire if they are of wood. But skids have more serious drawback still, according to us.

This brake was long in use on the *South Devon*, a line with steep gradients, and sharp curves. The skids could receive the whole load of the two pairs of wheels, leading and driving, between which they were placed. While asserting that this brake was very powerful, the engineers gave it up as far back as 1858 (*), on account of its destructive action on the road, and especially on the points and crossings. The stability of the engine was however in no way affected, no case of running off the line had occurred during the running of the skids, although in the origin these had no flange, and left the rails at times on sharp curves, a drawback which the addition of a small flange remedied. We have cited other engines provided with brakes of this kind, those of the *Giovi* and pointed out (II, 355) the destructive influence of the mode of action, not only on the rails, but even on a part of the tires.

Let us add however that the skid-brake has been kept in the tank-engines with eight wheels (II, 258) now devoted to working the Liège inclined planes, so that the engineers, who have had a long experience of this mode of action, are not unfavourable to it. The wheel-base, 14.76 feet, with wheels of 3.44 feet, left however, for the three spaces at the level of the centres, a total length of 4.45 feet, sufficient either for skids or for blocks.

251. *Crane-brake.* M. *Beugniot* was induced to complete the means of stopping for his steep gradient engines by a crane-brake; a disc keyed on to the middle of the leading axle was tightened up as usual by an iron strap. This brake, spreading the pressure over a great surface, offers positive advantages, especially when the action of the stopping means has to be much prolonged, a case in which the disadvantages of the ordinary brakes are much aggravated. But the expedient in question has a certain amount of complication against it, the extra effort of torsion put on the axle, and a reduction of power, the diameter of the disc being necessarily less than that of the tires. With counter-steam, which allows the ordinary engine-brake (if even it exists) to be reduced to an accidental and discontinuous part, blocks are preferable.

(*) Report of Colonel Yolland to the Board of Trade, 12th of June 1868.

CHAPTER IV.

TENDER-BRAKES.

252. The tender-brake is on account of the weight of that vehicle, at least with its full load and its position under the driver's hand, the principal brake of the train drawn. It is the one which comes in the openest and most actively, on the line where only a restricted part or none at all is given to counter-steam; and it is far too often tightened up to complete skidding of the wheels. A point is made of giving it a rapid and powerful action, and great solidity.

At the outset of railways, it was often considered sufficient (Pl. XI, *fig.* 5) to press in a block in the form of a wedge, K, between the wheels very close together, by means of a lever L. For great distances between centres, the block was replaced by two blocks hung from the frame, and pressed against the wheels by rods (*fig.* 6), a method still applied at the present day, and which with simplicity unites the advantage of distributing the pressure very nearly equally between the two blocks, in spite of very unequal wear. The screw has generally been substituted for the lever.

T being the tension brought on to the vertical shaft, α the angle it forms with the rods, their compression is $\frac{T}{2 \cos \alpha}$ and the effort normal to the wheels $\frac{T}{2}$ tang α. The angle α ought thus to be pretty open.

The principle which consists in taking from the *vis viva* of rotation, the work of screwing up the blocks, was applied first to tenders and under the simplest form, and that most favourable to rapidity of effect. The blocks were brought on directly by the tires. In the arrangement devised by M. *Tourasse* (Pl. XI, *fig.* 7), to a fixed support O, situated on the vertical through the centre, and above that point, is articulated a double lever carrying at the other end *b*, and also by a joint, a block S ; to scotch the wheels, the movement being in the direction of the arrow, it is sufficient to let go the lever, held up until then by the rod *t*. The block falls on the tire,

which carries it on by its friction, and tends to take it away from the axis O, on account of the eccentric position of the latter. The pressure, and with it the friction increasing very rapidly, skidding is produced with extreme rapidity. In order to act in both directions, either a second similar and independent lever is necessary, or a symmetrical appendage to the first, forming a complete system therewith, which works by means of a lever, either in one direction or the other.

This brake was soon given up. It skidded necessarily, and too fast, and it only acted on one pair of wheels; with two blocks, it only made use of one at a time.

The principle has been taken up again since, but has not been accepted excepting on condition of greatly modifying its action, as done first of all by M. *Tourasse* himself, in a variation (Pl. XII, *fig.* 17) which does not appear to have been applied, then by M. *Stillmant.*

M. Tourasse's modified brake acts on the two pairs of wheels, and in both directions. At rest, the axis *m n* of the cross-bar carrying the blocks is horizontal; in order to scotch the wheels, it must be made to rock over one way or the other, according to the direction of the train.

For movement in the direction of the arrow 1, the rod *h* is compressed, the block AA lifted, the block BB let down on to the tire; friction acts immediately to tighten the blocks, and left alone, it would go as far as skidding. The same effect in the direction of arrow 2, if the rod *h* is drawn, that is to say if the handle M is turned in the contrary direction.

The screw V does not thus serve to press the blocks on the tires, an effect which is produced by itself; its triple function is to put on the blocks, to check their displacement, and consequently their friction, and to undo them.

The change of direction to give the handle, according to the direction of running, that is to say, according as the engine has the tender behind or in front, is in this case, as in that of the reversing the valve-motion of engines (214) a serious objection. It is of consequence, in order to avoid all hesitation, all mistake on the part of the fireman, that the tightening of the brake should always be produced by the same direction of turning the handle. It is true that an error in this case does not prevent the brake being tightened up; but it would be done much slower, and would require a greater effort on the handle, as it would be against the action of the friction.

M. *Tourasse* proposed to add to this brake, which is particularly liable to skid the wheels, a small indicator which might be usefully applied to all the others. This is simply a cam *c* fixed on to an axle, and giving, as long as the latter turns, an oscillatory motion to a rod *l;* the relative slowness or

the suppression of this movement shows the driver if skidding is about to be reached, or passed. Only as it may be reached for one axle, without being so for the other, or for the others, it would be necessary for each of them to have its tell-tale, an amount of complication hardly admissible.

253. *Modes of working. Lever, rack, screw.* Hand-brakes are almost always worked by means of a screw, a convenient and sure organ which, with a low pitch, joins to the advantage of power, that of keeping on the tightening by itself, but with respect to which a certain amount of slowness is complained of. The lever acts more promptly; but, unless by having recourse to a more or less complicated combination, it is more difficult to obtain sufficient pressure on the blocks, by means of that organ, and the necessity of fixing the lever so as to keep the pressure on is a trouble. The use of the simple lever is thus restricted to certain categories of goods waggons. The rack acts rapidly, it remains fixed by itself in any position, by means of a pawl applied to the handle. During a certain time it was exclusively adopted for the tenders of the Eastern of France, where it was found to produce skidding in four seconds (that is to say in a distance from 215 to 230 feet, at the speed of 37 miles an hour) when the initial distance apart of the blocks and tires is from 0.47 to 0.60 inch.

The screw has however been adopted generally.

It can take a movement of translation under the action of the handle, or remain fixed, and then impart that movement to a nut.

M. *Ramsbottom's* tender (II, Pl. LXXXIII, *fig.* 3) offers an example of the first case. In the second, by far the most frequent (it is more convenient, in effect, for the working, that the plane of rotation of the handle should not displace), the screw may, either rest on a pedestal by means of a collar placed under the handle (Pl. LV, brake of the Ceinture (*Paris*) tank-engine; Pl. LXXXII, *fig.* 1, tender of the *Graffenstadt* engine; Pl. V (waggons) *figs.* 1 and 2), or else abut at the other end against a foot-step (Pl. III, *figs.* 2 to 6, horizontal screw; Pl. VII, *figs.* 12 and 13, vertical screw; Pl. XIII, *figs.* 4 and 5, *Stillmant's* brake; Pl. XIV, *fig.* 1; Pl. XV, *figs.* 6 and 7; Pl. XVI, *figs.* 7 and 8; etc...). The foot-step has the advantage of holding the screw up better, and of reducing the work of friction on its support to a minimum.

It is sometimes sought to render the action of the screw more rapid. See, for example (Pl. XII, figs. 14 and 15), the means applied some years ago to the Mediterranean tenders, a means analogous to the successive use of two plungers, which allows in hydraulic presses, the speed to be propor-

tioned to the intensity of the pressure, which is at first very slight. The shaft screwed on the lower portion, taken by the movable nut T of the lever, carries equally on the upper portion a reverse screw V, with a much greater pitch (0.35 inch for the latter, and 0.079 inch for the other). The upper screw is taken by a nut H (fig. 15), carrying a small collar pressed against the recess *e e* of the sheath, by a spiral spring ρ. As long as the tension of the shaft *a* is slight, the friction of the screw-threads of V cannot take on the nut, held by the friction due to the pressure of the spiral spring ρ. The movement of the shaft itself, being added then to the relative travel of the lower nut T, the latter travels at each turn, through the amount of the two pitches; the blocks come thus rapidly into contact with the tires. But at that instant, the effort on the handle, and the tension on *a* greatly increasing, the moment of the friction of the threads of the screw against those of the nut H overcomes the friction of the small collar *e;* the nut is taken on by the rotatory movement of the shaft, the lower screw with low pitch alone acts, and the thing comes under ordinary conditions.

254. *Stilmant's brake.* Under its first form, this brake belonged unreservedly, too unreservedly indeed, to the category of apparatus in which the blocks are tightened up by the friction itself. Bringing the blocks on was produced, as it still is indeed, by wedge. The blocks were hung from the frame, one of them forming the extremity of a rod BB, inclined to the line of centres of the wheels (Pl. XII, fig. 10). The other block and the other extremity of the rod carried inclined planes, jointed, between which a screw allowed a wedge C to work; as soon as the latter was the very least tightened, the vehicle running in the direction of the arrow, the front wheel tended to take the rod on, carried by the suspension-rods with oval holes, and reducing its obliquity. This was, in principle, the first *Tourasse* brake, the mode of action of which, in conformity with the ideas in vogue at a certain period, was not long in being more thoroughly appreciated. It was rigorously a brake for *mishaps*, but not a brake for regular service, which ought to be simple and handy.

For the reverse movement, besides, taking the blocks on by the friction acted not as a powerful aid, but as a resistance which had to be overcome by the screw. This circumstance, troublesome enough for tenders which habitually run only in one direction, was much more so for waggons which have to run in both. It is thus by greatly reducing the obliquity of the rod which carries the blocks, and consequently the action, sometimes favourable, sometimes the contrary, of taking on the blocks by the fric-

tion, that this brake has been able to enter into the domain of practice. It has received in effect, numerous applications; particularly to the tenders of the Western of France, of the Eastern, and of the Northern (Pl. XII, *fig.* 11).

Its distinctive features are: the combination of the screw and the lever working a wedge, and especially by the happy arrangement of that organ C, formed of two jointed branches which tend to become parallel, by the very fact of tightening up, as well as the slides applied either to the blocks themselves, or to the rods which press them. The acuteness of the wedge thus increases gradually.

With these alterations, the blocks are taken along with sufficient force, and the inequalities in the two directions become bearable. If skidding is sometimes difficult to be avoided in the favourable direction, the screws allows of a series of skidding and unskidding being performed. M. *Vuillemin* mentions a van of the Eastern of France, the wheels of which ran 8184 miles, and were skidded more than eight hundred times, without showing any flat place on the tires.

" Those which are formed in a stoppage are, " says he, " effaced during the following stoppage, by the iron brake-blocks, which act like lathe tools, not cutting, but tearing off the substance and maintaining the shape perfectly round. "

The screw having only a slight effort to transmit to the lever, may have a high pitch; it should besides have in that case two threads, in order that a nut of moderate length, may have sufficient bearing surface; but, as the shaft of the handle might turn under the influence of the vibrations and of the lever and the appendage, it is desirable to apply a ratchet to the handle.

255. The figured sketches (*figs.* 1 to 5, Pl. XIII) give six tender-brakes of the Western of France, with four wheels, all with suspended brake-blocks.

Figure 18 (Pl. XII) represents a Mediterranean tender with six wheels and eight blocks carried on cross-beams. This brake is complicated and slow on account of the flexion of the numerous parts and the time lost at the joints. It is besides not all that could be desired as regards distribution, the pressure on the intermediate pair, which is the least loaded, rising to 4.52 tons, while it is 3.00 tons on the front and 2.56 tons behind.

A tender-brake exhibited at *Vienna* in 1873 (engine of the General Society for working railways, *Tubize* line, Pl. XII, *fig.* 16) showed a detail worth following: the working shaft O is there carried by a one of the pairs of blocks, an arrangement indicated naturally when the blocks are suspended to the

body, and the distance between the wheels sufficiently reduced for the length of the rods which work the other pair of blocks not to be excessive.

One word now as to the examples, very few in number, for which it appeared sufficient to find a place in the atlas of vol. II.

Pl. LXIX. Tank-engine of the Eastern of France. In this six-wheeled tender, really an engine without the boiler, a block has been applied to each of the extreme wheels. The total effort has thus been spread over four points, although the coupling allows it to be applied to two points only, as is thus done the most part of the time. Each of the extreme wheels acts in stopping the middle one, by its coupling-rod, as the second acts on the first ones for traction.

Pl. LXXVII, fig. 5. Modified *Engerth* of the *Creuzot* (II, 351). Each of the four wheels of the articulated truck is pressed at two diametrically opposite points. The two blocks of the same wheel are tightened up by a cranked lever worked by the screw; the axis of rotation of this lever rests on the inside block, and its second arm transmits the pressure to the outside rod by means of a rod.

Pl. LXXXIII, figs. 1 and 2. Four-wheeled tender of the four-wheeled *Graffenstaden* engine. Here again, each of the four-wheels is taken on both sides. The big upper rod worked by the screw handle *m* acts on each of the two right hand blocks, by a cranked lever having, as in the preceding case, its axis of rotation on that block, and the pressure is transmitted to the two left hand blocks by the small rods jointed on to the lower arms of the cranked levers.

The equality, or more correctly speaking, the constancy of the distribution is only incompletely insured by the taking up holes of the blocks, made at one end of the big rod and of the small lower rods. There is besides in this mechanism a cause of unequal distribution from which the preceding one is exempt, that is the influence of the tension of the big draw-rod. We shall return to this detail on the subject of waggon-brakes (260).

CHAPTER V.

CARRIAGE AND WAGGON BRAKES.

§ 1st. — General observations.

256. Few subjects have exercised the skill of inventors so much as brakes, especially carriage-brakes. During many years, railway companies were constantly harassed with inventions, and nine times out of ten, there was a brake in question. As besides in France, the government is always first applied to (the more so as it is often a question of getting an experiment made at the cost of the State, or at any rate an official recommendation,) the first thing done was to offer the novelty of the idea to the Minister of Public Works. Thus, how many boxes are crammed with papers and reports on brakes, reports almost negative, need hardly be said. Not that the idea is always absurd, but it is rarely practical, and if practical, rarely new. In general, it is especially persons absolutely unacquainted with railways, and even with elementary notions of mechanics, who are possessed by the demon of invention, and by the laudable desire of protecting their fellows against the dangers which threaten them on railways. Those who are a little up in the question are more reserved; the others go into it with all the candour of ignorance, and invent either impossible brakes, or brakes which already invented many a time, will be so again.

By confining ourselves to brakes already applied, or which have been the object of serious tests, we should find a very considerable number; but many present only insignificant differences. It will be sufficient to describe briefly some examples, the more so as, if it is too absolute to say, as is sometimes done, that the simplest brakes are the best, simplicity is at least one of the essential conditions which they have to fulfil.

The rolling stock of important lines is always divided in two great classes: high speed, and low speed.

The latter has a relative simplicity of construction which extends natu-

rally to the brakes; but it is not only in consequence of a sort of harmony between the elements that it should be so. High speed stock (passenger-carriages, luggage-vans, etc.), runs little beyond the systems to which it belongs. When, by exception, it gets on to other systems, it finds there a sufficient and experienced staff, and besides it makes but short stays thereon.

It is not the same thing as regards slow goods stock.

Although the common distance has not yet taken in France all the development which might have been expected, the carrying stock makes long journeys and long stays beyond the system to which it belongs and complicated, delicate, or little used mechanism, is then exposed to miss the careful attention which is necessary for it, or to be very badly received, if it is of a nature to modify the ordinary composition of the trains. This consideration must be taken into account before introducing into the low speed stock of a line arrangements which might be out of their element on others, or even be absolutely excluded therefrom, as was done in the case of M. *Guérin's* automotor brake, which the German boards refused to allow on their trains. This is one of the motives which determined the Eastern of France to give up that system (297).

The maintenance of foreign stock is limited in general to what is indispensable for keeping it in running order. On the Eastern of France for example :

" It is formally prohibited to do any repairs to foreign rolling stock, beyond what are strictly necessary for the safety of the running of the trains (art. 66 of general order n° 6). "

A rule which is abrogated, however, for certain companies, in virtue of special agreements.

252. *Importance of means of stopping goods-trains.* We should deceive ourselves, however, if we saw in the greatest simplicity admitted and even demanded by goods-brakes, a consequence of their less importance. The speed of goods-trains is doubtless low, and, from that point of view, a power relatively less of the whole means of stopping, suffices for them. But this difference of speed disappears in a great measure on heavy inclines. On the other hand if, in itself, a goods-train dreads accidents, collisions less; if at any rate they are less serious for it than for a passenger-train, these accidents are often reciprocal. If a goods-train cannot be kept in check, running down an incline, or if, going up, the breakage of a coupling allows part of the train to run backwards, it is very often a passenger-

train which has to undergo the consequences. The brakes of goods trains, especially on lines of great traffic, are thus not of less importance than those of passenger trains; and it is indispensable to give them, particularly on heavy lines, a sufficient power for every eventuality, without however increasing excessively the staff of the train.

This is managed, for example, by coupling, look-out to look-out two waggons, the brakes of which are worked by the same man, making great use, when the gradients allow, of lever brakes (272, 273) etc...

The blocks may also, in the low speed stock, be hung from the frame, without hesitation, the uncomfortable trepidations for passengers which result therefrom, being then of no consequence.

Like starting too sharp (II, 125), too sudden stoppages may also produce breakages of couplings, not directly of course, but by the reaction of the buffer springs. It is of consequence, in order to diminish the intensity of this effect, to facilitate the expansion of the train at the two ends, by causing the resistance to disappear, offered by the engine, or, with greater reason, by the engines, to the expansion at the head. Hence the instruction always addressed to drivers, for example, in the following terms, taken from a service order (5th of April 1866) of the locomotive department of the Eastern of France :

" It is necessary that the drivers should avoid stopping abruptly, and that, when compelled to do so by signal, they disengage, immediately after the stoppage, the brake or brakes of the tender, in order that the engine or engines may offer no obstacle to the recoil movement resulting from the reaction of the buffers.

" When the brakes have been put on in front of a signal to stop, and if the signal is taken off before complete stopping, and the train has to go on again, the driver, after having had the brakes taken off, will allow the train to go on for some time under the impulse of the acquired velocity, and will only open his regulator, after having made sure that the springs have gone back. "

258. *Wheels taken by two blocks.* — Considerable importance is attached in Germany to acting on each wheel by two blocks symmetrically opposed : it seems preferable, in effect, to withdraw the guard plates and especially the journals of vehicles with brakes from the very considerable strains developed by the play of those organs. If a wheel carrying a weight P is skidded by the horizontal pressure π of a single block, the horizontal effort on the journal is $\pi + f\,P$ if the block precedes the wheel, and $\pi - f\,P$ if it follows the wheel. Thus in a vehicle with four wheels skidded, with equal values of P and π, it is the first axle which undergoes the most considerable

strain if the blocks are external to the wheels, and the second if they are internal.

Supposing the coefficients of the friction of the tires against the blocks, and against the rails to be equal, π ought to be at most equal to P, and the strains are P $(1+f)$, P $(1-f)$; or, for $f=0.25$, a value often reached, 1.25 P and 0.75 P.

For a wheel pressed equally on both sides (which is rare), that is to say by a force $\frac{P}{2}$, the increase of strain on the journals is reduced to f P, or 0.25 P. The position of the journal would be more favourable still, with a single block applied at the summit of the wheel.

The application of the pressure to each wheel, by means of two blocks diametrically opposed, involves considerable complication, without well ascertained advantages. It only saves the journal, that is to say, the part of which it is easy to prevent the breakage, by a sufficient dimension, favourable at the same time for the lubrication. It is very necessary to act on both wheels of the same pair, but sufficient to act on one point of each wheel, at the present time especially, when a point is made of avoiding skidding, and consequently to limit the pressure.

Divers types.

259. Examples contained in the atlas of vol. II.

Pl. I, fig. 7. Carriage of the N. E. of Switzerland; blocks hung from the bodies; one on each wheel; rod worked by a screw with movable nut; conical gearing and a handle.

The brake of the carriage of les Dombes (Pl. VII, figs. 12 and 13) is the same.

Pl. II. Carriage of the Indian Branch Railways. Each of the six wheels is taken by two blocks, hung on to the axle-boxes, an arrangement almost obligatory on account of the convergent play given to the wheels (II, 187). This apparatus belongs at the same time to the category of transmission-brakes, but under the simplest conditions. The great length and consequently small number of vehicles, the absence of buffing springs and the invariability of the distances between centres, allowed of the efforts being transmitted to the blocks by simple draw-rods.

Pl. III. figs. 1 to 6. Passenger stock of the Algerian lines. The four blocks, independent of the body, are supported by cross-beams placed on the axle-boxes. The working shaft is suspended from the cross-beams by small rods which, by their inclining to the vertical, make up for the inequality of wear of the two blocks of the same side, and thus insure not the equality, but the constancy of the distribution of the pressures.

Pl. V, figs. 1 and 2. *Reifert's* double suspension carriage. The four wheels are taken on the two sides by two blocks s, s, suspended from the frame. The suspension pieces

are caps embracing the large wooden blocks, which project on the outside, and which, small stirrups, provided with pressure-screws, allow of setting back as they become worn.

The extremities of the left hand caps (fig. 2) support the working shafts; on the extremities of the right hand ones, the tightening-rods are jointed.

Pl. XIII, fig. 1. Luggage-vans of the Austrian State railways. The wheels are pressed on both sides by blocks suspended from the frames, as well as the working shaft.

Do. fig. 4. Custom House luggage and goods van of the Eastern of France. Stilmant's brake with screw (movable nut) and lever, working four metal blocks.

Pl. XIV. Horse-boxes (figs. 8 to 13) and open trucks (figs. 18 to 23) of the Algerian lines. The block is jointed on to the lever arm of a cranked lever, the upper arm of which, widened out has holes in it for taking up the wear of the block, and to which the big working lever is connected by means of a pin.

260. *Brake with cross-beams and eight blocks of the Lyons six-wheeled carriages.* (Pl. XI, *fig.* 9). The middle wheels are acted on on both sides; an arrangement with little reason in itself, seeing that these wheels are less loaded than the end ones (II, 9), and which simply results from the fact that the starting point is the type of the brake with cross-beams, for four-wheeled carriages adapted for carriages with six wheels.

The effort t of the screw is divided equally, by the movable nut $m\ n$ forming a beam between the two rods $m\ p$, $n\ q$.

θ and θ' being the compression strains on the rods, α their inclination to the horizontal, l the working lever $q\ O$, and d the equal lengths Oa, Ob, the equilibrium of the shaft O, taken by oval holes in the cross-beams, or better suspended by two small rods, gives :

$$2\ (\theta - \theta)\cos\alpha = \frac{1}{2}\ ;\ \text{and}\ \frac{1}{2} \times l = 2\ (\theta + \theta')\ d\ \sin\alpha\ ,$$

whence

$$\theta - \theta' = \frac{t}{4\cos\alpha}\ ,\quad \theta + \theta' = \frac{t \times l}{4\ d\ \sin\alpha}\ ,$$

and

$$\theta = \frac{1}{8}\ t\left(\frac{1}{\cos\alpha} + \frac{l}{d\ \sin\alpha}\right),\quad \theta' = \frac{1}{8}\ t\left(-\frac{1}{1\cos\alpha} + \frac{l}{d\ \sin\alpha}\right).$$

The pressures are :

$$\text{On every block A,}\quad \theta\cos\alpha = \frac{1}{8}\ t\left(1 + \frac{l}{d\tan\alpha}\right),$$

$$\text{Id.}\qquad \text{B,}\quad \theta\cos\alpha = \frac{1}{8}\ t\left(-1 + \frac{l}{d\tan\alpha}\right).$$

Every thing else being equal, the difference $\frac{1}{4}\ t$ of these two pressures is so much the less, the smaller t is, and, consequently the leverage Oq greater. The sum of the pressures on the eight blocks, is :

$$4\ (\theta + \theta')\cos\alpha = \frac{t\ \ l}{d\,\text{tang}\ \alpha}$$

a value which ought not to exceed P, the weight of the vehicle.

Figure 12 (Pl. XII) represents a luggage-van of the Northern of France with Stilmant's brake, which however differs only by a little more simplicity from the apparatus applied to tenders (*fig.* 11).

261. *Capstan brake of American double bogie vehicles.* — For these great vehicles, the programme included : the application of a block to each of the eight wheels, forming two groups with variable angular positions; the opposition of the efforts in each group acts in such a manner that there is no pressure on the turning pin : the working of the brake, done at either end of the vehicle indifferently, the conductor, in this stock with central passage, keeping not in the look-outs, but sometimes on one, sometimes on the other end platform, and having, at need, to act on two consecutive vehicles.

The whole of these conditions is fulfilled very simply by an arrangement, the germ of which is the old diligence apparatus, which only skidded the hind wheels. A glance at figure 20 (Pl. XIII) is sufficient to understand it.

The lower portion of the working shaft carries a *barrel b* with decreasing radius, in the grooves of which a piece of chain is wound. MN is a beam, hanging freely by a clip RR, below the frame, and to which are attached the four rods 1, 2, 4, and 6, the latter symmetrical with 1, serving only when the working is done at B, in the same way that 1 serves only when the working is done at A.

T being the tension of the working rod 1, T′ the tension of 2, r the ratio of the arms of the lever $\alpha\ \beta$, and consequently T′ r the tension of 3; T'' the tension of 4, and $T''' r$ that of 5, the equilibrium of the beam M N gives, neglecting the slight want of parallelism of the rods,

$$T' = T + T'',$$

and

$$T \times MO = T'' \times OH,$$

whence

$$T' = T.\frac{MH}{OH}, \quad \text{and} \quad T'' = T\frac{MO}{OH}.$$

The pressures on the corresponding blocks for a given value of T, are then :

$$\text{On the pair} \begin{cases} aa', (1+r)\,T'' = (1+r)\,T.\dfrac{MO}{OH}, \\ bb', \ldots\ldots\ T''r = \ldots\ r\,T.\dfrac{MO}{OH}, \\ cc', \ldots\ldots\ rT' = \ldots\ rT'.\dfrac{MH}{OH}, \\ dd', (1+r)\,T' = (1+r)\,T.\dfrac{MH}{OH}. \end{cases}$$

The group situated opposite the working side, is thus that which receives the greatest pressures, seeing that M H is necessarily > M O.

In the same way, in each of the groups, the inside pair is the least pressed : if the arms of the beams $\alpha\beta$, $\gamma\delta$ are equal $r = 1$, and the pressure on that pair is only the one half of that on the end pair.

P being the load of one pair of wheels on the rails, the maximum tension T of the rod

1 is given by the condition that the effort on the pair the least pressed, that is to say $(b\ b')\ r\ \mathrm{T}.\ \frac{\mathrm{MO}}{\mathrm{OH}} = \text{almost P, or } \mathrm{T} = \frac{\mathrm{P.\ OH}}{\mathrm{OM.}\ r}$.

The inequality of the distribution, which is all the less the smaller T is, but always inevitable, is, however, made up for by the simplicity of the mechanism.

The action of this brake is very prompt; it reaches its limit very rapidly. But this limit, that is to say the sum total of the pressures on the blocks, is relatively low; the value which the screw handle can give, although much slower, would require a much more considerable effort than the capstan.

Besides, the load, per pair of wheels, being generally less in American stock than in European stock, it is quite natural, and indeed necessary, that the maximum pressure on the blocks should be less also.

One of the principal things attended to at present, with respect to brakes, as we have seen (248), is to avoid prolonged skidding of the wheels, without requiring continual work on the part of the men, a succession of skiddings and unskiddings, difficult to obtain without strict supervision. This advantage of a very prompt, but very limited action, without possible skidding, has recently determined the *Cologne* and *Minden* line to apply to passenger carriages, with six wheels and central passage, a brake founded on the preceding one, but only having blocks on the end wheels (Pl. XI, *fig.* 10), and provided also with double working apparatus, dispensing with turning the vehicles, so as to put the consecutive brakes at the disposition of the same guard. One turn, or even three quarters of a turn, are sufficient for putting the brake on, and the finger has only to be removed from the ratchet, to take it off instantaneously. It is well to note the somewhat frequent tendency to give up the screw. The same result would however be arrived at by increasing its pitch, doubling the threads, and applying a ratchet to the handle.

Brake of carriages of the old temporary Mont-Cenis line. — In the six-wheeled carriages constructed according to Mr. Brunlees's plans for the temporary line over Mont-Cenis (II, Pl. XIII, *figs.* 8 and 9), the mechanism for guiding the axles necessarily required the application of two blocks to each wheel. Of course the central rail was not neglected, which, when necessary for traction, was not less so for stopping. Each carriage had thus two independent brakes, one with jaws taking the central rod; the other with blocks on the wheels. They were both worked by means of wheels and axles. But we shall not dwell on these details of a stock no longer existing, and now of course without interest.

Figures 7 to 17 of plate XIII give the figured outlines of the divers screw-brakes of the Western of France vehicles.

262. *Hand-brakes, with the work of putting on partly stored up.* — The work necessary for promptly bringing on, and even for a certain amount of tightening up of the blocks, can be stored up, either by the elevation of a weight, as in the *Bricogne* brake, or by the tension of a spring, as in the simple arrangement due to M. *Lapeyrie.*

Brakes with counter-weights. — The multiplicity of express trains on the Northern of France, their speed, and the general activity of the traffic, made the necessity felt long since on that line, of powerful brakes, with very prompt action. Thus brakes with counter-weights, studied with much care and success by the engineer of the carrying stock, M. *Bricogne*, have received numerous applications, particularly to the vans of the trains, both passengers and goods. All the brake-vans are weighted; the amount for those of passenger trains is 2.10 tons; and they are often six-wheeled, and their end wheels only are acted on. The goods brake-vans, the body of which, taken up in great part by the staff, and the working of the brakes, only takes a very small useful load, about 1 ton, have much more ballast; the whole floor is, so to say, paved with cast-iron plates, and the weight of the vehicle empty, amounts to 12 tons.

The tightening up of the blocks is produced: 1st, by the fall of the weight, which varies, the weight of the lever included, from 175 to 330 lbs; 2nd, by the action of the guard on the handle.

Several arrangements have been applied on the Northern of France.

1st. The brake shaft *o*, (Pl. XI, *fig.* 11) is worked by a long lever L, at the extremity of which first acts the weight P, then the supplementary tightening up by hand. The weight, connected with a lever by a rod with an oval joint, keeps it suspended, as long as it is itself retained at the top of its travel; as soon as it is let go, it falls, and the lever with it; the guard then turns the fly-wheel V, and presses the vertical shaft *o* more and more on the lever.

The total pressure on the blocks, obtained by this apparatus, is as follows:

1. *Action of the weight,* of 286.6 lbs.

Ratio of the big lever L to the levers λ, λ, of the block spindle.	12.50	
Pressure due to the dead weight 286.6×125		1.600 tons.

2. *Action of the guard, with a pressure of* 44 *lbs on the wheel.*

Ratio between circumference of wheel and pitch of screw.	7.95	
do. the big and small levers of the shaft (as above).	12.50	
do. final: $7\ 95 \times 12.50$	99.37	
Effort on the four blocks: 99.37×44.		1.956
Total pressure. . . . . Inches		3.556

A figure very rapidly reached, and which may be afterwards exceeded, if the guard continues to tighten with a greater effort than 44 lbs.

The total pressure indicated, which is scarcely more than the one third of the load on the rails, is however a minimum. During the shock, the pressure of the parts, and of the blocks, the velocity of which is abruptly destroyed, exceeds that which corresponds to simple statical equilibrium, as supposed by the preceding estimate, although the passive resistances are not taken into account therein; and it continues to exceed it after the shock, the double ratchet opposing the reaction due to the elasticity of the pieces, as we shall see just now.

For equality of work stored up by raising the weight, the final pressure on the blocks would be all the greater, the heavier the weight, and consequently the height of fall less. But for the mechanism described, with direct action of the weight on a lever solidly connected with it, this fall has a determinate value : the distance travelled by the extremity of the lever, necessary for bringing the blocks into contact with the wheels, in making up for the bending and deformation of the parts. As the weight itself must give, in the state of statical equilibrium, a determinate pressure on the blocks, the work follows.

This work is dispersed mainly in vibrations of the parts, the alteration of the substances in the region of the shocks and the passive resistances only absorbing a small portion :

2nd. The mechanism of the brake proper is arranged as in the apparatus previously described (260, 261); that is to say that the blocks are tightened by an effort of traction applied to a horizontal rod *b* (*fig.* 12), jointed on to a short lever *l* nearly vertical, keyed on the shaft O of the blocks; the action of the weight ought thus, like the man's hand, which it precedes and prepares for, impart to the vertical shaft *a* of the handle V, a movement of rotation. Such is the function of the rack B of the counter-weight, and of the conical gearing K. The movement of *a* is, in its turn, transmitted to the draw-rod of the lever of the shaft O by a pinion P and a rack C; it could be equally so by a conical gearing and a horizontal screw with a movable nut.

Figure 13 shows the application of the same principle to luggage-vans on roller axle-boxes (II, 79), and where it was, on that account, necessary to take the wheel on both sides.

3rd. In the arrangement prevailing at the present day, the conical gearing, by which the weight transmits the movement to the fly-wheel shaft, has disappeared. The weight, in two parts symmetrically placed on each side

of the shaft, is supported by a nut, through which passes a cylindrical enlargement of the handle-shaft; on this enlargement is cut a screw with very long pitch, and with three threads. As soon as the weight is let go, it falls sliding on this inclined plane. Kept up by vertical guides against which it is applied by means of rollers, it cannot turn, so that it is the shaft which turns, with uniformly accelerated velocity. When, as in passenger-vans, the tightening apparatus is placed at the middle of the body, it cannot act directly on a lever keyed on to the block-shaft, the length of the lever being in that case too small, would require an excessive counter-weight. A rack and pinion transmit then the movement to a lever from the shaft, nearly vertical.

4th. But this direct action becomes possible when the counter-weight and the working are put over into a box at the end of the body, the lever then having a great length. Such is the case with the goods-waggons; their arrangement is represented by *figs.* 11 to 13 of Pl. XVI; the screw-shaft *a*, *a*, rests on the footstep *c* bolted to the frame. The counter-weight is formed of the two parts P, P, fixed at the top of the nut E, E and at the bottom, by the pin *j*, to the big lever L. When the weight has arrived at the bottom of its travel, the nut has still hold of the screw V, and the latter, still turning on account of its acquired velocity, continues to press the weight on the lever. When it has come to a stand, the guard tightens up if required, by acting on the wheel; the taking off is done by turning the contrary way. This mechanism which reduces the number of parts to a minimum, is simple and efficient.

The apparatus for letting go is represented in plan by figure 9 (Pl. XV), in which the full lines refer to the position of rest (the counter-weight at the top of its travel), and the dotted lines to its fall, and to the position of tightening. This apparatus as we see, includes a double ratchet. Two ratchet-wheels *r*, R, are keyed on to the shaft *a*. By giving the handle *p* an angular movement of 65°, the guard produces two effects : 1st he sets free the ratchet of the lower wheel R, which restores to the shaft a freedom to turn ; 2nd he puts on the ratchet *q* on to the teeth of the upper wheel *r*, which are the contrary way, and thus opposes reverse rotation, which would otherwise be produced during the second part of the shock due to the fall of the counter-weight, and of the lever solidly connected therewith. In order to overcome this reaction better, the number of teeth in the *counter-ratchet r*, has been multiplied as much as their solidity would allow; it is three times greater than that of the teeth of the detaching wheel R.

5th. Figures 1 to 3, Pl. XVI, represent a high speed van, provided with

a counter-weight brake, the counter-weight being at the same time the motive apparatus of a Newall's transmission-brake.

The whole of the mechanism being arranged with the view of this transmission, which is described farther on (280), it would be superfluous to dwell here on the tightening up of the van *alone*, for which this mechanism would not be required.

Exter's brake. The oldest of the weight-brakes is *Exter's*, dating from 1847; always acting on two vehicles at least, it belongs to the category of transmission-brakes (275), and is arranged accordingly. Hence the use of a cord as intermedium between the weight and the wheel on the one part, and on the other, the big lever which works the brake in each vehicle. The cord is wound round an axle, and, in the contrary direction, the chain to which the weight is attached. In order to act on a single vehicle, the cord passing over a roller placed at the extremity of the lever, would simply end on a fixed point F; but the direct action of the weight and of the fly-wheel, adopted by M. *Bricogne*, is in that case much simpler. We shall return (278) to this brake, such as it is still in action to the present day.

Applied so long ago in Bavaria, where the gradients are steep, the principle of the motive weight has not spread in the north of Germany, where it inspired even at first a certain amount of mistrust. I saw in 1852, a carriage which the *Leipsic* and *Dresden* company, had had constructed for the king of Saxony; the brake could be put on by the fall of a weight placed in a double partition; but the weight could not be set free excepting by means of a key which was in charge of a sort of special chamberlain. In case of need, would he have dared to take upon himself to make use of it, and would he have done so in time?

M. *Lapeyrie's* brake (Pl. XIV, fig. 6). Round a cast-iron sheath G which surrounds the shaft a, is wound a spiral spring formed of a thick steel wire fixed by the bottom to the sheath by means of the screw V, and at the top to a ring K, K, which can slide lengthways of the shaft by the action of the tension of the spring, but which the guides g, g, prevent from turning.

By taking off the brake, the guard tightens the spring, taken on by the rotation of the shaft, by means of the socket m, and sheath G.

A pawl and ratchet wheel r, keyed on the shaft immediately below the handle m, prevent the unloosening of the spring. The guard goes as far as the limit of the tension, which corresponds to the normal distance apart of the blocks and the wheels.

In order to put the brake on, the guard has only to undo the pawl. The spring being able to expand only below, takes along with it the shaft a, to which its impulses impart an accelerate velocity. The blocks are put on and pressed by the forces of inertia of the parts, the velocity of which is abruptly destroyed; so that the blocks are not only put on, but tightened and the guard has to complete the effect, by acting on the handle; a fraction of a turn is enough.

The socket m, fixed by a pin to the shaft, toothed like that of the sheath $\alpha\beta\gamma\delta$, serves

to regulate the tension of the spring, when its elasticity has become altered by work. It is sufficient to raise the sheath G a little, to make it turn more or less, according to the degree to which the spring has been loosened, and to let it go again; the teeth take hold of themselves, and fix the sheath and the spring in that new position.

This additional mechanism, which only costs about fifty shillings, accelerates the action of the brakes remarkably.

Whichever mode may be employed, tension of a spring, or better, the raising of a weight, it is quite logical to bring on in this way at least a portion of the tightening up work, which by its nature is hurried, over the taking off, for which the guard can take his time.

263. *M. Tabuteau* has substituted for the screw, a combination of the lever BCA and the knee EDF. (Pl. XI, fig. 8). The action is prompt and powerful, when the mechanism is in good order; but in this respect, it is somewhat delicate. It requires besides, a considerable travel of the point of application of the guard's effort; a drawback which can be got over as has been done on the Southern, by making a counter-weight act on the lever, the guard having only to complete the action by a slight displacement of the handle. But this arrangement comes to grief, when it acts well, by skidding, on account of the rapid progression of the pressure at F, and thence of the tension of the rod *t*, when the angle EDF of the knee has become very open. It has thus less chance than ever of getting into vogue at the present time, seeing that a point is made not only of avoiding skidding, but even (which perhaps is too much) to render skidding impossible. M. *Bricogne's* counter-weight, or M. Lapeyrie's spring, remedy very well the slowness complained of in the screw, preferable then to the combinations of levers.

264. Let us now examine two other improvements of detail of secondary interest, but which would be placed naturally with the preceding (Pl. XI, *fig.* 14).

1st. *Means of preventing an excessive return of the blocks, when the brakes are taken off.* With the simple screw, it is of consequence, in order to avoid the loss of time on tightening up, only to turn it, when taking the brakes off, the necessary number of turns strictly necessary. It is easy to limit the descent of the driving nut E, by a stop *a*; but this stop cannot be fixed, especially with wooden blocks. What should be invariable, is the distance from the block to the wheel when off, and consequently the travel of the nut E. But this constant length, which it travels on the screw, changes; it rises as the blocks wear; the stop *a* should thus follow the changed position. This movement can be made in automatic way, not quite continuous, but by degrees close enough.

The stop *a* is an enlargement of a bar *b b* suspended to a pawl *d*, which takes into the teeth *c*, *c*. The bar passes through the nut E, and terminates in a head *t*, placed at a distance from *a* equal to the sum of the normal travel of the nut and of its thickness. When the apparatus has just been adjusted, the nut is in contact by its lower face with *a* when the brake is taken off, and by its upper face with *t*, when the brake is on. Then, when a slight wear of the block requires the nut to go up a little higher for tightening, it takes with it the rod *b*, which rises by the height of one tooth, and is kept in that

new position by the pawl d, until a fresh amount of wear requires and brings about another rise.

This small apparatus was introduced in 1856, by *M. Lindner*, on the Austrian State lines.

2nd. *Means of rendering skidding impossible.* On the Lower Silesia and the Mark line, M. *Wöhler* proposed to prevent, not the excessive slackening, but excessive tightening; and as it is less a useless strain of the parts that has to be prevented, than rendering the skidding of the wheels impossible, the limit of the pressure ought to be, not constant, but nearly proportional to the load of the wheel on the rail. The maximum pressure on the screw V V on its footstep c ought thus to increase with the load on the journal (Pl. XI, fig. 3).

The footstep s, instead of being fixed, is connected to the extremity of the neighbouring suspension spring by the two levers $m\ n\ p$, $q\ r\ s$.

When the brake is not in action, the footstep exerts on the screw, and the latter on its collar, an effort : $\frac{P}{2} \times \frac{mn}{np} \times \frac{qr}{rs}$, P being the load on the wheel; as the guard screws up the handle, an increasing fraction of the effort comes on to the nut E and the rod b.

The ratios of the arms of the two levers and those of the pieces which transmit the pressure to the blocks are such, that when the effort of the footstep is brought entirely on to the nut E, the pressure of the blocks has a value k P, k being a given coefficient, < 1. Should that value be exceeded, equilibrium being disturbed, the footstep gives way under the screw; and this movement is at the same time immediately stopped by the application of the bracket t fixed to the screw-shaft, on to the stop e fixed to the body, the projection t rendering any ulterior rotation impossible.

This solution is ingenious; but without reckoning the new pieces it requires, such dependence between the parts of the suspension and those for working the brake is scarcely admissible.

It is one of those improvements, a little far-fetched, which an inventor's influence may get accepted on a certain line, but which hardly extend beyond.

Mr *Adams* proposed long since a sledge-brake, which has often been reintroduced since (Pl. XII, *fig.* 9). The blocks are wrought-iron wedges c, c', provided with flanges and pressed between the wheels and the rail. The friction of the rail tends to send in the one block farther and farther, and to send out the other. As they are connected together, these two contrary actions balance by the intermedium of the parts of the mechanism.

There is only one step from this brake to M. Laignel's (Pl. XI, *figs.* 15 and 16), which was long in action on the Liege inclined planes; but the first has the advantage of utilizing, at the limit, the whole weight of the vehicle, the weight of the wheels, which are slightly lifted, being comprised.

The skid-brake was afterwards reproduced by M. *Didier*, with an improvement, good in principle, seeing that it consists in storing up the tightening work, in such a way as to render the action extremely prompt.

The skids are hung from the frame. By setting free a ratchet wheel,

and on account of the particular arrangement of the spring hangers, the springs cease to bear, and the body, falling literally, brings down its skids on to the rails.

It would be superfluous to dwell farther on skid-brakes, which are dangerous especially at the crossing of the appurtenances of the permanent way. Experience proves besides that, suitably put into operation, brakes which act on the wheels are more powerful than those which act on the rails.

265. *Special brakes for low speed vehicles.* Figures 1, 2 and 3, of Plate XIV, represent the brakes of three types of closed waggons H*if*, for low speed trains (classification of the Lyons system). These brakes, with inside box, and four blocks on cross-beams, only differ in the details of the working; in the first, the handle M and the screw-shaft *a* are vertical; the first thus acts on the second by a conical gearing. In the second, the handle is vertical, the screw-shaft *a* horizontal, and their difference of level is made up for by an intermediate shaft *b*, and two conical gearings. In the third, the arrangement is the same, excepting as to the horizontal position of the handle, which suppresses the upper gearing.

The blocks when off, being 0.39 inch from the tires, the following is for each of these types, in the way of example, the number of turns of the wheel necessary to bring them into contact :

No. 1. Length of the tightening levers (*ab*) . . . . . 0.26 ft.; travel 0.39 inch.
do. shaft (*ac*) . . . . . 0.98 » 1.50 »
Return levers (*de*) . . . . . 0.79 » 1.50 »
do. (*df*) . . . . . 0.95 » 1.81 »

Pitch of the screw, 0.24 in. Number of turns . . . . $\frac{1.81}{0.24} = 7.07$ turns.

The possible travel of the nut E on the screw is . . . . . 0.98 ft.
Corresponding number of turns 50

No. 2. Length of the tightening levers (*ab*) . . . . . 0.26 ft.; travel 0.39 inch.
do. shaft (*ac*) . . . . 0.96 » 1 50 »

Pitch of the screw, 0.32 in. Number of turns . . . . . $\frac{1.50}{0.32} = 4.8$ turns.

Number of turns of the vertical shaft *b* : $4.8 \times \frac{21}{15} = 6.7$ do.

Number of turns of the wheel (the two upper wheels having the same number of teeth) . . . . . 6.7 turns.
The possible travel of the nut E on the screw is . . . . . 1.30 inch.
Corresponding number of turns . . . . . 41.0 »

No. 3. Length of the tightening levers (*ab*) . . . . . 0.33 ft.; travel 3.94 in.
do. shaft (*ac*) . . . . . 0.98 » 1.18 »

Pitch of the screw, 0.32 in. Number of turns . . . . $\frac{1.18}{0.32} = 3.8$ turns.

Number of turns of the wheel 3.8 also, the two wheels having the same number of teeth.

The screw-brakes of low speed stock frequently differ only from those of high speed stock, by the more general suspension of the blocks to the frame (examples : II, Pl. XV, *figs.* 4 to 8 ; Pl. XVI, *figs.* 7 to 12). In these two types, eight blocks constrain on each side, each of the four wheels.

We shall not multiply the examples of screw-brakes with several blocks. They are costly and heavy, and especially they require a guard and a look-out.

It is often useful, and indeed indispensable, to apply brakes to a more or less considerable proportion of unmounted stock. This is necessary, especially for waggons which run on branches with steep gradients, which is so often the case with colliery lines. The brakes are in that case lever ones. It is not only with regard to waggons while running, but to those standing. We shall return to this point (272, 273).

§ III. — Nature of the blocks.

266. *Wooden blocks and metal blocks.* Wood, particulary poplar, was long in sole use. But its disadvantages were made manifest, on account of the necessity, more and more evident, of avoiding skidding, and of the increasing number of long and heavy inclines.

The exclusion of skidding (248), involves, on these latter, the exclusion of wooden blocks, when counter-steam does not replace, or at least does not reduce the action of the brakes. The blocks would wear out with extreme rapidity, and would even frequently take fire. They have often had to be replaced, after each crossing of the *Brenner*, and at times during the course of a single journey. These effects may, it is said, be avoided by limiting the pressure on the blocks (that is to say by multiplying the brakes), and in taking advantage of favourable changes of gradient, to take the brakes off, and let the parts have time to cool. But that is easier said than done. The substitution of metal for wood was thus induced; metal being much more economical in general, and more favourable to the preservation of the tjres, which heat and loosen less, the metal blocks withdrawing the heat caused by the friction, better on account of their conductibility.

Metal is very often preferred at the present time, even on other sections than those on which a very prolonged action of the brakes is required; and that from a fact which at first sight seems to constitute an inferiority : that under ordinary atmospheric conditions, the coefficient of friction on the tire is less with metal than with wood. Skidding is less to be feared, with

guards who are careless, or have a mechanism to work with, which distributes the pressure badly over the blocks.

As to the choice to make, between cast-iron, wrought-iron, and cast-steel, opinions generally agree as to the exclusion of the third, but are divided, although unequally, between the two first. M. Gottschalk gives the preference to wrought-iron on account af its relative softness. On the Lower Silesia, and the Mark line, wrought-iron appears to wear the tires more than cast. The Upper Silesia has adopted hardened cast-iron, or rather a mixture of cast-iron ant cast steel prepared by M. *Glockner*.

Some special tests have been made with the view of deciding this question, one which concerns economy as well as safety :

1st. *Eastern of France. Experiments of MM. Vuillemin, Guébhard and Dieudonné* (*). The trial train included : 1st, the engine; 2nd, the dynamometer-carriage; 3rd, a brake-waggon, with wooden blocks in one case, and cast-iron in the other.

The tests were made in two ways : 1st, as was done by M. *Poirée*, drawing at a uniform velocity, the brake being tight on;

2nd, the train being brought to a determined velocity, the regulator of the engine was closed and the brake put on, at a given signal.

The resistance was : for wooden blocks, 0.218, and, for cast-iron blocks, 0.192 of the load on the rails.

But this difference is not solely imputable to the nature of the blocks; there was, in effect, another difference, besides that between the substances: the wheels, skidded by the wooden blocks, continued to turn with the iron ones. The influence of this circumstance was indeed that which the experimenters chiefly proposed to ascertain; so their conclusion is :

" Thus, a much more considerable effect may be obtained from a brake, by letting the wheels turn to a certain extent, than by completely stopping them. "

But it would be much more legitimate, if the tests, with and without skidding, had been made with blocks of the same nature.

2nd. *Main and Weser line.* A luggage-van with lever-brake received successively, blocks in wood, wrought-iron and cast-iron; it was placed on an incline against the first distance-post, and left to the action of gravity, during very calm weather. When opposite the second post, at 831 yards from the first, the brake was put on, by letting go a weight. The distances

(*) *De la résistance des trains.* Page 85, note F.

run over were : 1 (wood) : 1.20 (wrought-iron) : 1.21 (cast-iron). This inferiority did not prevent the adoption of cast-iron blocks, which last ten times as long as wooden ones, and which are made use of just as they come out of the mould, while the wooden ones require fitting.

3rd. *Wilhelm's Bahn.* Two coal-waggons, equally loaded, one with wooden blocks, the other with wrought-iron blocks, were coupled on, and let go on an incline. Sometimes the one, sometimes the other brake, was brought into action, always at the same point, and the distance run measured. It was, on the average, 1.49 times greater with the wrought-iron than with the wooden blocks.

These observations are in accordance with those resulting from the practice of the Westphalia line. " The guards know perfectly ", they say, " that in order to obtain the same retarding force, they have to exert more force with the wrought-iron than with the wooden blocks; when they have the choice they always prefer the latter. " There is thus no hesitation as to accepting the consequences of these facts, that is to say that more brakes are necessary with iron blocks than with wooden ones. The first have at the same time the advantage of saving the tires more. As to cast-iron, it lasts much less time than wrought-iron, and it seems necessary to abandon it.

4th. To these conclusions may be opposed that of the tests made on the Hanover lines (which had only reference however to engine-brakes : shunting engines). The effort on the handle, necessary to produce skidding, would be no greater, according to these tests with wrought-iron than with wood ; and the first would give a more uniform wear of the tires, and would keep their section better. The first point, which seems at the same time little in accordance with the second, may be partly explained by the particular form of the wrought-iron blocks, which take hold of the flange (Pl. XI, fig. 21), while the wooden blocks were only applied, as ordinarily on to the tire. The first act thus only on elements of the wheel animated by a greater velocity, which might have compensated for the inferiority of the coefficient of friction.

This form of metal block is looked on as very useful from the point of view of the running of the engine, especially through points and crossings. It does not produce, in effect, on the edge of the flange, as does the wooden block pressing only the tire, a projecting edge, which produces trepidations in the engine, when the rolling line changes its position on the tire. But it would seem hardly practicable to admit this *profil envelope* for all the blocks, as it would have to be adapted to tires at different degrees of wear, and consequently to very different projections of the flange.

5th. On the *Altona* and *Kiel* and *Lubeck* and *Buchen* lines, it is admitted as in Hanover, that wrought-iron, eight times more durable than wood, gives, for the same effort on the handle, the same retarding force in ordinary weather, and a greater force when the weather is damp.

Without dwelling further on this, we find in this case again, on the points of fact, these divergences of results, and consequently of opinions which only surprise persons little acquainted with questions of practical mechanics. These discordances are explained by the different conditions under which the observations have been obtained, and by varieties in the nature of the substances acted on.

What appears very nearly established, is, that metal ought to be preferred to wood; it costs less, deteriorates the tires less, and gives a more constant friction, because it is less affected by atmospheric changes; and these advantages seem to make up for a certain inferiority of action.

The frequent want of success of cast-iron, seems at the same time to arise from its having been badly chosen, sometimes failing from too much, sometimes from too little hardness. The experiments made hitherto are not sufficient for defining with any precision the conditions which it should fulfil, and which are besides, not absolute, but relative.

One objection has been brought forward against metal. Experience would show that a block applied to a wheel of a little less diameter than its own, and thence bearing only at its middle, gives very reduced friction.

The independence of the friction on the surfaces is only an empirical law, true between certain limits. We know by examples already quoted, that of the *Cochot's* brake, with long skids, among others (II, 207), that starting from a certain point, the friction diminishes when the surface increases. This fact may have its set off, that is to say the diminution of the friction below a certain limit of surface; the influence of the excess of contact cannot however be separated from that of the nature of the substances in action, and of the specific pressure, which modifies the state of the surfaces, polished or rough. However that may be, by admitting the fact enunciated and consequently the necessity of moulding the outline of the block to that of the wheel, it is remarked that, with wood, this adaptation is easy (it effects itself besides, and rapidly by wear) while with metal it requires expensive fitting.

This is less a serious objection, than a small infliction of no great consequence : the assortment of the blocks and the wheels. Moreover, when it

is the pair of wheels which is replaced, it generally is so, by a pair less worn, and consequently of greater diameter, so that the block takes, not by the middle but by the extremities, which, as would appear, would not give rise to the same objection.

The two assertions are difficult to reconcile; but their correctness is doubtful; as regards friction especially, before deducing consequences from observations, it is necessary to make sure that they have been multiplied sufficiently, and do not amount only to simple anomalies.

CHAPTER VI.

COMPOSITION OF TRAINS AS FAR AS REGARDS FITTED BRAKES

§ 1st. **Examples. — Regulations**

267. Nothing is more elementary than to reply to the various questions which can be put on the subject of brakes; to determine for example, the relative number, under given conditions of section, speed, and of distance to be run before stopping, provided however that the values to be given to the coefficients of adhesion and resistance be settled on. It is necessary, were it only from the uncertainty reigning in this respect, to know what goes on. It is often desired to dispense with calculations, even the most simple; but even with the facts, it is always wise to verify their results, by comparing them with those sanctioned by experience, in identical, or at least, analogous circumstances.

In general, the determination of the number of brakes applies to the train *drawn*, and without taking into account the resources which may be offered by the locomotive, either by means of counter-steam, or of a special brake. As to the tender, its brake is, of course, in addition to those of the train drawn.

The number is fixed without making any distinction between double and single lines. A train which goes off may, it is true, have more serious consequences in the second case than in the first; if it runs through a crossing station, it may go into a train coming in the other direction(*). But the object and the results of measures of safety should be to prevent accidents, and not simply to palliate the consequences, more or less. Besides, a collision between trains in contrary directions, is sometimes, in reality, less serious, in spite of the great relative velocity, than if the trains

(*) The 23th of July 1871, a goods train descending the *Tarare* incline (Rhône), and which was not able to be stopped at Amplepuis, dashed into a passenger train coming the other way.

were running in the same direction. In the first case, in effect, the train run into is protected by the mass of its engine.

Ballast in brake-waggons. The retarding force of a brake-waggon is proportional to its weight. It is thus not the relative number of brakes which should be fixed, but the fraction of the total weight drawn, susceptible of being skidded. The proportion of the numbers of the waggons supposes that of the weight. The case must then be provided for, in which the brake-waggons are empty, or slightly loaded.

Luggage-vans, which form part of passenger-trains, have only at certain periods of the year, a very low useful load. Thus on certain lines, on the Northern of France, among others (262), they have a permanent load, in the shape of cast-iron ballast. The variable load gives an increase of security.

As to passenger-carriages, their load is relatively low and less variable, especially for the first class, to which however, brakes are rarely applied, unless in express trains which contain few if any carriages of other classes. These apparatus are naturally brought on to the 2nd and 3rd class carriages, in order to remove the annoyance caused by the jerking of the brakes, from the passengers paying high fares. For 3rd class carriages, with 50 places, the difference between the weights of the vehicle full and empty exceeds 3 tons, but these two extremes are rare enough for the amount of the load to be neglected.

A brake-*carriage* counts thus for a brake, always, full or empty.

It would not be the same for goods-waggons, lighter as regards dead weight, while their useful load varies from 0 to 10 tons, and unfortunately, speaking economically, the first is a frequent case. The load must thus be taken into account. As every thing cannot evidently be complicated by " distinctions without a difference ", only two states are distinguished : empty waggons, full waggons. The Mediterranean regulation, for example, has (art. 60) :

" Brake-waggons forming the regulation number to prescribe as minimum for *goods-trains* ought always to be loaded or ballasted. However, two empty waggons provided with brakes, may, at need, replace a brake-waggon loaded or ballasted. "

It is clear that a waggon very little loaded ought to be considered as empty, that a waggon, the load of which is not greatly inferior to its normal load, ought to be considered as full. It is a question of common sense and good faith.

The same regulation adds, what is however only a consequence of the equivalence established (art. 61) :

" The figures which fix the proportions in which brake-waggons ought to enter into the composition of goods-trains, apply to the case where the trains are exclusively composed of loaded waggons. For trains containing empty stock, the minimum number of brakes ought to be calculated by counting two empty waggons as one full one. "

It is only a question, in these two clauses, of *goods-trains;* not that low speed waggons, loaded or not, may not enter into the composition of passenger-trains; but it is clear that the companies have no interest in running empty low speed waggons in these trains, and that the movement of distribution of that stock ought to be effected by goods-trains.

On the Eastern of France, the point in question is regulated in these terms (circular No. 40, of the 22nd of June 1870, art. 12).

" Every brake-waggon, empty or not ballasted, counts for one half" (one is ten tons). " The loads, ballast and useful weights, ought to be added together; but account is only taken of goods passing from one relay station or branch, to another relay or branch station. "

Lines of the German Union. It is now a long time since the Union of German railways adopted, for the number of axles provided with brakes, the following proportions correlative to the rates of inclination :

INCLINATION.	PASSENGER AND MIXED.	GOODS-TRAINS.
0,0020 or one in 500	1/8	1/12
0,0033 » 300	1/6	1/10
0,0050 » 200	1/5	1/8
0,0100 » 109	1/4	1/7
0,0167 » 60	1/3	1/5
0,0250 » 40	1/2	1/4

They were rendered compulsory in Prussia by the general regulation of the 1st of July 1868 (*).

1st. Maximum speed (art. 25).

Lines with gradients of more than one in 200, and radius of curves more than 100 yards, at least :

Express 60 miles an hour; ordinary 45; and goods 28 miles an hour.

The limit of 60 miles an hour is only admitted on condition of increasing by 1 the number of brakes given in the first column, and of excluding eight-wheeled vehicles from the trains.

(*) Allgemeine Bestimmungen zur Sicherung des Betriebs.

The above maxima are absolute, and cannot be exceeded under any pretext, not even for making up lost time.

Up gradients, and on stiffer curves, these maxima " shall be reduced "; the regulation limits itself to laying down the principle, but without any particular stipulation.

At first sight, the number of brake-waggons does not seem to take the velocity sufficiently into account. But the total number of waggons being so much less, the higher the limit of speed of the train, the influence of the constants, tender-brake, and if there is reason, engine-brake, becomes all the more marked.

The preceding rules have long been in force at the Semring and the Brenner; the proportional number of axles with brakes is thereon 1/2 for passenger-trains, and 1/4 for goods, on one in 40, at a speed of from 11 to 12 miles an hour for the first, and 9 to 10 for the second. It is only 18 miles an hour for imperial trains.

Giovi incline. — On the Giovi incline (II, 417), one in 35 on the average, the number of brakes, which is equally 1/2 for passenger-trains, is 1/3 for goods, which at the same time, have always an engine behind.

In principle, the costly organization of local brake-services is avoided as much as possible. From time to time, it has however to be resorted to on the Giovi. When there are many waggons at *Busalla* to bring down, and too few brakes, the regulation number is completed by adding loaded brake-waggons to the train, making afresh the double journey between *Busalla* and *Pontedecimo*. This accidental function is performed at need, by waggons loaded with ballast. The distances run by waggons is thus notably increased at certain periods, on that section of line.

Mediterranean system. — A local staff of brakesmen can only be dispensed with on the steep gradients which allow of the application of lever-brakes, not provided with any apparatus for working. If the regulation number of brakes has to be obtained by waggons utilized for traffic, and only running the distances assigned to them, these waggons are only fitted with apparatus, when they act as brakes. On the line from *Alais* to *Brioude*, for example, the heavy gradients (one in 40) of which are concentrated between *Villefort* and *la Levade* (19 miles), there is a special staff of brakesmen between these two points, residing at the foot of the incline, at *la Levade;* they go on to *Villefort* in front of the trains, which they accompany on the descent.

It can be easily understood what interest there would be in getting rid of this necessity for a supplementary staff, by mechanical means, which would at the same time find constant application on ordinary gradients.

However, economy, very marked for goods-trains, would be less for passenger-trains, the work at stations not allowing much reduction of the train staff.

The following are the proportions adopted on the Mediterranean system, and brought into the regulations by a decision of the 8th of May 1873 :

NATURE of the trains.	NORMAL SPEEDS supposed uniform.	INCLINATIONS of up and down gradients.	PROPORTION.
Passenger and mixed.	34 miles an hour and below.	Up to one in 100.....	1/6
	34 to 25 miles an hour....	Up to one in 200.....	1/9
		Below one in 200 up to one in 100	1/8
		» 100 » 50	1/5
	25 miles an hour and below.	Up to one in 200.....	1/12
		Below one in 200 up to one in 100	1/10
		» 100 » 50	1/7
		» 50 » 38	1/5
		» 38 » 32	1/3
Goods with or without passengers.	19 miles an hour and below.	Up to one in 200.....	1/40
		Below one in 200 up to one in 100	1/20
		» 100 » 50	1/8
		» 50 » 38	1/5
		» 38 » 32	1/3

This table is nevertheless modified thus by the following clause, inserted in the same article (59) of the modified regulation :

" In all passenger and goods trains running up gradients higher than from one in 50 to one in 38, the number of brakes will be carried to one for every four vehicles, at least. The last half of each of these trains should always contain at least the one half of the number of brakes so calculated. "

The same order stipulates that, on inclines above one in 50, the velocities of the trains should never exceed the following limits :

Passengers...	Inclinations above one in 50 up to one in 38	25 miles.
	— — 38 — 32	22 id.
Goods.....		25 id.

The figure of 25 miles an hour, the excess of which, on gradients reaching one in 32, we brought out (II, 379), has thus been lowered to 22 miles, and in reality that itself is never reached.

In presence of the examples taken from the practice of the Austrian and Italian lines, it might be thought that the guarantees of safety on the French

lines are not inferior to what foreign lines of their own action lay down as necessary, and which the public regulations had only to sanction.

On the section from *Modane* to *St-Jean-de-Maurienne*, for example, on an ncline of one in 32, the fraction which can be braked, of the train drawn is fixed at [1/3, while it rises to 1/2 on the Austrian lines for inclinations of one in 40.

Eastern of France lines. It will be remembered that this system, from which the dismemberment inflicted on it by events, have taken away several of its steep gradient lines, was divided into eleven sections or *profiles*. Each line was classed in one of these profiles, according to the inclinations going upwards.

The minima numbers of brakes are thus fixed (circular of the 22nd of June 1870, art. 10):

1st. *Passengers.*	Profiles G, H.....	1/6 of the vehicles.
	Profiles I, K, L.....	1/3 —

That is to say, for a maximum of one in 38, the same figure as on the Mediterranean for a maximum of one in 32.

2nd. Mixed and goods. Art. II. The brake-unit is 10 tons (like the unit of load).

" The minima numbers of brake-units which mixed and goods trains ought to contain on the lines classified, going upwards, under profiles G, H, I, J, K and L, are the same on the ascent as on the descent.

" They are fixed by the following table, abstraction always made of the engines and tenders :

NATURE OF THE TRAINS.	LINES classed under following profiles :	PROPORTIONAL NUMBER of brake-units and load-units.
Mixed.....	G.....	1/10
	H.....	1/8
	I, K.....	1/6
	L.....	1/4
Goods.....	G.....	1/15
	H.....	1/10
	I.....	1/8
	K.....	1/6
	L.....	1/4

" Art. 15. On the ascent as on the descent, on the lines classed, on the ascent, under profiles G to L, the last vehicle of the train should always be provided with a brake.

" There can be no exception made to this rule unless a waggon, the couplings of which are broken on *one side*, has to be returned to a repairing shop. In this case, the waggon may be coupled on *empty*, behind the last brake.

" Art. 16. If more than two brakes enter into the composition, two of them should be

in the last third of the train. In any case, no more than two vehicles with brakes, should be coupled, the one after the other, if the brakes have to act simultaneously.

. . . . . .

" Art. 24. On the descent of inclines classed on the *ascent*, under profiles G to L, the speed of the trains of every nature, should never exceed that specified in the time-book, however much these trains may be late. In particular, for goods trains, their speed may in no case exceed the following limits :

On the inclines classed ascent under profiles	G, H,	14	miles	an hour
— — —	I, K	12	—	
— — under profile	L,	11	—	

" Art. 26. The guards and brakesmen should never take the brakes fully off on the descent. They should keep the blocks close enough to the wheels to be able to put them on completely, the most rapidly possible.

" As soon as the velocity exceeds the limits fixed by article 24, they should even tighten up the brakes without waiting for a signal from the driver. "

The arrangement laid down by article 63 of the Mediterranean regulations, is to be found also in the Eastern of France regulations :

" Art. 14. If the engine or one of the engines of a train ascending an incline is coupled on behind, two brake-vehicles empty or loaded full, are sufficient, whatever may be the load of the train. "

The word coupled should doubtless not be taken to the letter, for the coupling as we have seen (II, 377), is often not done.

" Art. 13. (Additional note).

In the case where, on certain sections, trains would be drawn in an irregular manner by two engines on the descent of an incline, the second engine may be counted as a *brake*. In this case, a special service order will determine the number of brakes which should enter into the composition of the train. "

This is a question of a sufficiently frequent case, and it is not easy to explain why the part of the engine as brake, has not been fixed once for all.

Western of France. This system, generally with flat gradients, presents however, on the *Fécamp* and *Coulibœuf* lines, inclinations of one in 67, and on the *Saint-Germain* line, an incline for two thirds of a mile, of one in 29 (II, 417).

On the first, there is one brake to five vehicles, two to nine, three to twelve, and so on, adding one brake for three vehicles.

On the third, the number of brakes is two to three vehicles, three to six, four to ten.

§ II. — Loads kept back by an engine, on a given section and uniform speed.

268. If counter-steam has not yet, in a general manner, a legal existence as a brake, if it does not allow the number of the brakes of the vehicles to be reduced, it allows when desired, their *use* to be reduced in a considerable proportion, to the great advantage of the tires and the rails. It allows, *a fortiori*, a step to be avoided, to which recourse is had frequently, through a prudence which could not always be taxed as excessive, that is to say the addition of brakes beyond the regulation number.

The power of all the means of action, which the eventuality of a prompt stoppage may demand, is never necessary when it is only a question of keeping, on the descents of inclines to a perceptibly uniform speed. Two modes of proceeding can then be adopted : to make use of all the brakes of the train, and tightening them a little, or of a part only, tightening them more.

The distribution of the total retarding force, over a great number of vehicles, is preferable to concentration, with respect to the preservation of the stock, and to the reactions. The second mode is however applied also :

Tables of the Mediterranean system. In order to guide the station people, and especially the train-men in the applications of the two classes of means of stopping, counter-steam and brakes, to the nearly uniform descent of trains down inclines, the locomotive department of the Mediterranean has drawn up tables, which give for each rate of inclination and for each speed, the weight which can be kept back, either by an engine or a brake-waggon.

As starting point, the retarding force is admitted to be for an engine, $\frac{1}{10}$ of its adherent weight, and for a waggon, the $\frac{1}{10}$ of its weight which can be acted on by the brakes, the action being, of course, pushed very nearly to skidding.

Lengthened experience proves this estimate to be almost always below the reality.

The loads have been calculated, starting therefrom, so that the excess of their component parallel to the road, over the resistance corresponding to the speed, should be equal to the retarding force indicated.

For engines, the loads which figure on the tables are the weights so cal-

culated, making deduction of the weight of the engine and tender, that is to say the loads drawn, or rather *held back*.

For brake-waggons, the weight is included in that of the load they retain.

The inclinations indicated are, as needs scarcely be said, the real and not the fictitious inclines, which figure in the tables of the loads drawn (II, 387, 389, 390).

By means of the table, it is immediately seen if a train, of given composition and on a given profile, can be maintained at a fixed velocity, by counter-steam only, and in case of insufficiency what number of brakes should be put on during the journey.

It is clear that, every thing else being the same, the load which an engine or a brake can keep back rapidly increases with the uniform velocity admitted, seeing that the accelerating force to be balanced, per unit of weight, is so much less.

Here, for example, is the table relating to the incline of one in 38 :

Loads in tons which the engines of various types and brake-waggons can keep in check at various speeds.

SPEEDS IN MILES AN HOUR.	9	12	15	18	22	25	28	31	34	37	40	43	46	49
Engines uncoupled.														
Series 1 to 76 ..... / 161 to 171	»	4	5	6	7	8	9	12	13	15	16	19	20	23
Engines with 4 wheels coupled.														
Series 101 to 160 ..... / 201 to 1.000	47	49	51	52	54	57	59	62	65	68	71	74	78	81
Engines with 6 wheels coupled.														
Series 1.001 to 1.400 ..... / 2.201 to 2 400 ..... / 2.401 to 2.402	71	73	76	79	83	85	89	93	»	»	»	»	»	»
Series 1.401 to 2.009 ..... / 2.403 to 2.409	99	101	104	108	112	115	123	126	»	»	»	»	«	»
Engines with 8 wheels coupled.														
Series 2.501 to 2.530	143	149	153	155	161	167	»	»	»	»	»	»	»	»
Brake-waggons.														
Screw, full or with ballast	44	45	45	46	47	49	50	51	52	54	55	53	»	»
do. empty	22	22	23	23	23	24	25	25	26	27	27	27	»	»
Lever, empty or full	11	11	11	11	11	12	12	12	13	13	13	13	»	»

Comparison of the tractive and holding-back powers. The sections from *Amplepuis* to *Tarare* and from *Tarare* to *Amplepuis*, with fictitious gradients of one in 45 for the loads on the ascent, are really one in 38. The above table applies then to them. If we compare it with the loads taken up by the engines (II, 391), we see that the loads *hold back* by the engines, inferior to the loads drawn, when the speed is very low, reach them, then exceed them greatly when the speed increases; which is quite natural, seeing that the speed, which increases the first, diminishes the second.

For engines with eight wheels coupled, for example, equality takes place (156 and 153 tons), for the speed of 15 miles, which is very nearly the normal speed of the engines in question.

The tables go no farther, for the engines of this series, than the speed of 25 miles an hour; the smallness of their wheels not allowing them to go farther without running the pistons too fast.

269. The proportion of brakes is fixed then with reference to the rate of inclination of the profile, and to the speed, without taking into account the means of stopping with which the engine itself may be provided.

When an engine with separate tender has itself a hand-brake, it would however be all the more reasonable to take that into account, the more powerful it is : in the same way, if a tank-engine can brake all its wheels, which is the case when they are all coupled, there are no grounds for simply treating that powerful brake, as an ordinary tender one. But such is the rule.

As to counter-steam, it has not hitherto, led to the modification of the number of brakes. The fire-box burnt, or a broken tube, may in effect, cause it to be found wanting.

Hand-brakes may themselves, also get out of order; but, admitting that the breaking of, or damage to a brake may be as probable as the breakage of a tube, the first accident only affects a less fraction of the whole means of stopping; the bad state of a brake involves at the same time, tangible responsibility, while the breakages of tubes are most frequently facts of *force majeure*, or looked on as such.

However, all things considered, the inequality of the risks seems slight enough for a regulation part to be assigned to the engine without scruple. The assimilation pure and simple, to brakes of the same brakeable weight, would be more logical perhaps than the excess part, which has been assigned to it, only in one particular case.

In the terms of the general regulation No. 2 of the Mediterranean :

" When a goods-train is drawn over sections with up gradients by two engines coupled the one in front, the other behind, the number of brakes may be reduced to two, whatever may be the composition of the train (art. 63). "

This measure is founded on the supposition that an engine behind a train in double traction, is an absolute guarantee against running down backwards, in case of the couplings breaking. An incorrect supposition, as the article before-mentioned only applies to the limit of gradient of one in 50, a limit which had not yet been exceeded, in 1866, on the system in question.

An order of the 8th of March 1873, completed that article by the addition of the following paragraph :

" On sections containing gradients higher than one in 50, the number of the brakes will remain fixed, at the minimum, even for trains thus drawn, at one brake for four vehicles, if the gradient is comprised between one in 38 and one in 32. Further, the second part of the train should always contain at least one half of the brakes so calculated."

According to article 64 of the same regulation, when a goods train is drawn by two engines coupled in front, the second engine *counts for two brakes*.

As long as the engine of a train, in single traction, does not count even for one brake, it is scarcely explainable how the second engine can count, and counts for two brakes, in a train with double traction, which may and should (II, 263) be twice as heavy.

On the other hand, when a train having an engine behind, passes from an up gradient on to a down one, it is of great advantage to place that engine in front. It happens thus that this engine, which behind had for effect the faculty of reducing the number of brakes to two, takes in front quite a different, absolute value, two brakes. This is difficult to justify.

§ III. — Question of the *maxima* of speed.

270. The French companies have been recently invited to draw up propositions with reference to the absolute maxima of velocity on the different profiles. It is difficult enough to reply to such a question, put in general terms : under the most favourable conditions, for example, that is to say on a horizontal and in a straight line, where commences the exaggeration of the velocity? That depends on the state of the permanent way, of the rolling-

stock, and on the length of the train. If every thing is in good order, there is nothing dangerous in the velocity itself from the point of view of material accidents, up to a limit the attainment of which is never practically useful. But if a rail, and especially if an axle should break, the speed may enhance the consequences of that fact remarkably, and the probability of breakage being much greater for the axles of low speed stock, even empty, than for those of high speed stock, the presence in the trains of low speed waggons is an essential element in fixing the maximum speed (II, 298, and *Additions*, p. 831).

Excepting in this case, the question is only susceptible of precise solution from one single point of view, that of the stoppage to be insured in all cases, in the limit of protection of the signals. This limit increases (between 875 and 1640 yards, sometimes even beyond) with the rate of inclination of the down gradient, but not enough for the maximum velocity not to decrease at the same time, and greatly.

The Syndicate of the companies has only drawn up, in reply to the invitation, incomplete propositions; they apply only to a rate of inclination of one in 100, at the most :

Express and mail, normal speed above	34 miles an hour	75
Omnibus and *messageries*.....	25 —	47
Mixed, and passenger-trains carrying goods		
Goods carrying passengers.	Normal speed, 19 to 25 miles No. of vehicles, up to 30.....	31
	Normal speed, 19 miles, No. of vehicles, up to 80.....	28

All that can be seen in these propositions, is the desire to reply, at least in part, to a question, assuredly very difficult, and to do so with great caution, that is to say without any pledge. According to the companies, the maxima which they accept, are " in use " on the lines where the inclines do not exceed one in 100. It is doubtless *theoretical* use that is meant; where and when has a speed of 75 miles an hour been admitted on inclinations reaching one in 100? A driver convicted of having run at 75 miles an hour, down the *Blaisy* inclines of one in 125, for example (where a strict supervision has been long in force for repressing the frequent tendency to the exaggeration of speed on moderate gradients), would he not have cause to repent of it? At 75 miles an hour, what would become of the guarantee of distant signals, placed at distances calculated for far lower speeds?

If the companies have abstained from expressing an opinion on " *the maximum limit of speed which the trains* may take without risk on inclines

above one in 100, that is that it depends ", they say, " on the motor stock employed. "

Doubtless; and also, on several other elements, and particularly on the number of brakes; or rather, it is the latter which should be modified and rendered less disproportionate with regard to the speed limit.

The imprudence or neglect of drivers must assuredly be prevented or repressed, and all exaggeration of speed avoided; but this exaggeration is in no way absolute : it results from a combination of circumstances inseparable from the figure reached, and which alone can give it its real character. On a good road, a flat gradient, and a long straight line, the driver may, without imprudence, reach a speed superior to that which would be dangerous and imprudent on a road less good, on a decided incline, and in a curve. It is a question of *kind*. In desiring to proceed by general measures, and taking only one element into account, the rate of inclination of the profile, limits are necessarily fixed, as by the companies, the exaggeration of which takes away all signification from them. Far from combating the principle of maxima of speed, we consider it necessary, but it only appears to us applicable on condition of handing over the execution of it to the companies, leaving to them the care of applying to each section the figure suitable thereto, and the faculty of modifying it not only from one point to another, but from one period to another.

271. *Utility of apparatus registering speeds.* A simple infraction would only be possible, in that case, by disciplinary penalties, but the object would be gained, on one condition however. The exaggerations of speed are very difficult to verify; and, in case of accident, when there is occasion to believe that too great a speed may have had a certain share therein, it is often very difficult to ascertain, even by the minutest inquiry, what has been the maximum attained, and at what point.

The application to locomotives, of apparatus registering the velocity has been tried long since, and with a success which has not however been able to overcome the resistance which it gives rise to. The technical supervision and the accounts of the two departments of traction and carrying, already require such a multiplicity of verifications and writing, that a further complication is regarded with hesitation. It must not however be exaggerated. There are many stationary engines which have a permanent recorder of work done; it would be a little more difficult, doubtless to apply a speed indicator to locomotives, but at the same time the results would be far more important.

MM. Deniel and Quillet's tachometer. Among the examples which we could bring forward to call attention to a question perhaps too little observed, we should give the preference to an apparatus which is one of the oldest, if not the oldest of all, the *tachometer* of MM. *Deniel* and *Quillet*, which was at work for several months on the line from *Montereau* to *Troyes* (Pl. XV, *figs.* 3 to 6).

One of the engine axles transmits a movement of rotation to a horizontal axis C, carrying two rings, the one E, fixed on the spindle, the other E′ able to slide thereon, and connected together by four springs with balls D, D. For each velocity of rotation, the springs acted on by the centrifugal force of the balls bulge out, and the movable ring E′ goes more and more from its initial position.

Its displacements are transmitted to a pencil L, pressed against a card K, fixed to a disc, to which a uniform rotation is given by clockwork.

The card (*figs.* 4, 5, 6) has a double division; one radial giving the time, the other concentric, giving the velocities. The largest circumference corresponds to the velocity *nil*, the others to velocities which are so much the greater, the smaller the radius. The duration of the revolution of the card should be at least equal to the length of time the engine runs at one stretch, four, six hours, for example. The whole is inclosed in a box B, B, fixed on the side of the boiler. Behind a glass, is placed a dial graduated for the speeds, and in front of which works an index hand *f* (*fig.* 6), receiving movement from the lever λ, and a chain *c* (*figs.* 3 and 4). The driver has thus under his eyes the velocity attained at each instant. The curve of the movement gives the whole series of speeds, and the precise instant at which each of them has been attained. At a very low speed, that is to say below 6 or 7 miles an hour, the centrifugal force is too slight to deform the springs, which are applied against the rings with a little pressure. These small speeds are not thus given numerically by the apparatus, which is not sensitive enough, but they are not however confounded with rest. It was sufficient for this to incline to the axis the plane by which the ring E′ is applied against a shoulder on the bearing. As soon as there is a very slow motion, and consequently rotation, the ring always in contact then with the shoulder, performs a backwards and forwards movement, which is transmitted to the pencil, and the latter makes a sort of blot *p*, *p* (*figs.* 5 and 6) formed by small ordinates very close together. Each portion of curve commences and finishes by a blot, the one corresponding to starting, the other to stopping.

The duration of the stoppages is given by the arc comprised between the

end of one portion of curve and the origin of the following, but the trace gives also the employment of the time. For an absolute stoppage, the pencil has followed the circumference of velocity *nil*. If during the stoppage operations have been performed, a blot indicates the origin and the end of each of them.

The diagram is, in a word, a witness which reveals under a very simple form, all the circumstances of the running of the train; which betrays, if there is occasion, the *relative* exaggerations of speed, by pointing out the precise moment when the maxima have been exceeded; which allows the disputes which often arise between the locomotive and traffic departments, as to the employment of the time of the engines in stations, to be settled.

Figure 7 is the reproduction, half size, of the curve of the running of a train from *Montereau* to *Troyes*, and the speed of which reached at two instants only, 45 miles an hour.

The curve (fig. 8) refers to a run of 25 minutes made by an engine alone, and during which the velocity was made to vary abruptly, in order to ascertain the fidelity with which the indications of the instrument followed these variations of speed.

As to the details of execution, the concentration, on small circumferences, of high speeds which require particularly an exact measure, as regards amount and duration, is not very convenient; the transmission of the movement of the axle to the axis of the apparatus with the balls, by means of a cord and pulley π, π (*fig.* 4) raises objections also, which the application of a small strainer with roller would doubtless be sufficient to remove; but a transmission by rods and cog-wheels would perhaps be preferable.

However that may be, registering apparatus are too much neglected by railways. They seem to be feared, but why? because they are liable to get out of order? Of course, in case of derangement, their indications are of no value. The electric telegraph, is that not also subject to get out of order? Does that however prevent the railways making use of it, and deriving immense services from it? So perfect a machine as a railway, should make more use of auxiliary apparatus, which do not require the delicate mechanism of scientific instruments. In case of dereliction, instruments of this kind define responsibility. But, beyond those whom their indications might compromise, who would dream of complaining of them for what would be on the contrary their principal cause of existence?

Apparatus on trial in Germany. These apparatus meet with much less indifference in Germany, where the turn of mind of the engineers leads them more willingly to this kind of observations, rendered at the same time easier by the generally less active state of the traffic.

1st. *M. Holtz. M. Holtz's dynamograph*, introduced in 1857 on the Eastern of Prussia, and which registers the efforts of traction and the principal circumstances of the running of the trains, was also applied, but with unequal success, to the Lower Silesia and the Mark, to the *Breslau-Schweidnitz-Freiburg*, and to the *Berlin* and *Hamburg* lines.

2nd. *Samman's* speed controller has been the object of lengthened trials on the Eastern of France, the Northern of Austria, the *Altona* and *Kiel*, the *Magdeburg* and *Leipsic*, and so on; which trials are still going on.

3rd. An apparatus constructed in the company's shops, and which gives the approximate measures of the speeds, is applied, on the *Cologne* and *Minden* line, to most passenger-engines, and to some goods and shunting engines.

4th. *M. Kramer.* A *Kramer's* speed indicator gives, on the Palatinate line, results which appear very satisfactory; but they have been less fortunate hitherto on the Hanover lines, where they are not able yet to avoid the apparatus getting frequently out of order, nor to make the transmission by strings, like that of MM. Deniel and Quillet's indicator, work regularly.

Instead of giving the speeds directly, other apparatus, much more convenient for reading, are, such as *Scholz's*, which is being tried on the *Berlin* and *Anhalt* line, simple tell-tales which register the number of turns of the driving-axle corresponding to each division of time.

5th. MM. *Guébhard* and *Tronchon.* The Southern and the State lines, in Austria, are trying a very simple little apparatus, due to two French engineers, MM. *Guébhard* and *Tronchon*, who introduced it on the Eastern of France. It is founded on the vibrations imparted to a vertical pencil simply guided, by the trepidations, more or less jerky, according as the velocity is greater or less, of the vehicle carrying it. If the point of the pencil is very lightly applied to a strip of paper rolled round a horizontal drum, and animated with a movement of rotation, it traces thereon at rest, a thin and continuous line; if the vehicle is in motion, the pencil oscillates, comes periodically on the paper, in virtue of its rapidly destroyed descending velocities, and traces a line, the breadth of which, increasing with the speed may serve as a measure of the latter.

The paper, the movement of which is uniform, has straight lines on it at equal distances, normal to the direction of its movement, and which give the division of the time. In the tell-tales of the Eastern of France, the minute is represented by an interval of 0,06 inch. In order that the pencil should not return, at each new revolution of the drum, on the line corresponding to the preceding revolution, it receives, from a little tra-

veller, worked by the moving mechanism of the drum, a motion parallel to the latter, and thus traces, not a circumference but a helix.

The passage of a train or of an engine on one line, is clearly indicated by the apparatus of a train standing on the other line. An apparatus set up in a fixed position, would thus register the precise time of the passing of the trains, and even their velocity.

The indications given by this little instrument are at the same time complex; for the same pencil, the thickness of the stroke is evidently a function not only of the speed, but also of the construction and state of the vehicle, as well as of the state of the road; the pencil line only gives a measure of the speed for the same apparatus, the same vehicle, the same permanent way.

It is, by that very fact, very suitable for representing the comparative state of the various roads, on condition of running with the same vehicle and at the same speed. For some years, the German engineers have been seeking a means of making in this way a verification of the state of the roads, *on the journey*. Since the beginning of 1872, the *Brunswick* lines have been traversed, at least every two months, by a special waggon carrying two apparatus (M. Claus's) giving, the one the speeds, the other the state of the road. This example is followed on the *Magdeburg* and *Leipsic*, and the Main-Weser lines; this mode of verification, which points out very simply the defective points, those where the sleepers should be lifted, appears to be highly appreciated by the maintenance staff, who find therein a sure guide. It will probably become usual.

It must be remarked however, that the conditions of the ground plan of the line, have an influence, which must be taken into account, on the indications of apparatus founded, like that of MM. *Guébhard* and *Tronchon*, on the intensity of the trepidations.

On sharp curves, and especially, without doubt, on entering and leaving, these indications, for equality of speed, are not comparable to those given by the instrument on a straight line.

§ IV. — Rules relative to the use of brakes without working apparatus. Examples.

272. The position of inclines, the special nature and constancy of the traffic, as well as the direction of the running with load, often allow, as has been already said (265), safety and economy to be combined by taking advantage of lever-brakes, with two blocks and even one only, which have at the same time in themselves, the advantage of costing little (Pl. XII, *fig.* 13,

Stilmant's brake, and Pl. XIV, *figs.* 4, 5, 7, 8 and 9). It will be useful to point out some examples of these special conditions.

At the summit of a long incline at a pretty nearly constant rate, the insufficiency of the brakes with working apparatus, is compensated, and the number of brakesmen reduced, by putting a suitable number of lever-brakes, the tightening of which is graduated by the position of the notch under which the lever is locked.

If the number of waggons provided with brakes of this kind is great enough for each of them to have only to furnish a slight contingent of retarding force, it is sufficient to let down the levers, without locking them in the racks; in that case they act by their weight only.

As skidding should never be reached, it is well to render it impossible. On the Central Swiss, the lever has been made purposely thin and flexible, so that, at the last notch, skidding is still far off. But it comes to the same thing with rigid bars, to reduce the number of notches.

Examples. Mediterranean system. 1st. Up gradient from *Beaucaire* to *les Firminelles* (*Tarascon* and *Cette* line) : rate of inclination, one in 143, length 5 miles.

All the trains contain a certain number of coal-waggons, all provided with lever-brakes. The trains pull up at the summit of the gradient, and the driver has a settled number of levers let down, without being tightened, never exceeding one to four waggons. Trains with 80 loaded waggons, descend the incline to the regulation speed of 18 miles an hour at the most, with twenty brakes let down.

2nd. Up gradient from *Nîmes* to *le Mas-de-Ponge :* rate of inclination, one in 83, length 5 miles.

On the ascent, all the goods-trains are worked by two engines, one of which is behind. The use of the lever-brakes is unnecessary.

On the descent, the trains, three quarters made up of coal-waggons, have two engines; they stop at the summit of the incline; there, the driver makes the fireman let down the number of brakes he thinks requisite, according to the load or the state of the rails For eighty waggons, for example, he lets down thirty brakes, ten of which are tightened.

Local circumstances may lead to regulate the way in which lever-waggons are to be placed in the train. Thus in order to facilitate the operations of sorting by gravity, which are performed at the *Terrenoire* and *Rive-de-Gier* stations, the stations where the trains are formed, should take care that the levers are placed, on each line, relatively to the direction run in, on the side prescribed by the circular No. 98 (4th of Nov. 1865).

Maximum number of waggons in goods-trains. The maximum number of waggons comprised in a goods-train may also be modified in certain circumstances, and particu larly on account of the use of lever-brakes.

A minute of the 25th of June 1868 fixes the maximum in question thus:

	MAXIMUM NUMBER OF WAGGONS DRAWN.	
	Train drawn by one engine.	Train drawn by two engines.
Section with gradients of one in 200 at most.....	80	80
do. do. 200 to one in 125	70	80
do. do. 125 100	60	80
do. do. 100 67	50	70
do. do. 67 50	40	50

These figures refer to loaded waggons. For trains containing empty stock, two empty waggons count for one loaded, but without the total real number being able to exceed eighty without special authorization.

" On certain sections presenting steeper inclines than one in 125, goods-trains may be composed of a number of waggons superior to the limits fixed by the preceding table, without however the maximum of eighty being exceeded. These exceptions, which should be subject to the observation of particular precautions, are the object of special instructions. "

It is by application of this latter arrangement that another minute (24th of Febr. 1870) has :

" The numbers indicated in the preceding table may be increased by ten, without however the number of eighty being exceeded, in the cases, and on condition of the precautions, as follows :

1st. On the sections from *Saint-Étienne* to *Rive-de-Gier*, and from *Saint-Étienne* to *Firminy* (maximum rate of inclination one in 67), on condition of letting down the brake-levers of *one half* at least of the waggons in excess of the numbers given in the table;

2nd. On the sections from *Roanne* to *Balbigny*, and from *la Fouillouse* to *Saint-Étienne* (maximum rate of inclination, one in 77), on condition of letting down the brake-levers of *one third* at least of the waggons in excess of the numbers given in the table;

3rd. On the section from *Rive-de-Gier* to *Givors* (maximum rate of inclination one in 143), on condition of letting down the levers of the brakes on *one quarter* at least of the waggons in excess of the number given in the tables.

Further :

4th. On the section from *Saint-Étienne* to *Firminy* (maximum rate of inclination one in 71), the number of loaded waggons composing a goods-train drawn by a single engine may be carried, by exception, to eighty, on condition that the number of brakesmen be increased by one for every five waggons, for the waggons in excess of fifty given in the table;

5th. On the section of *Saint-Germain-des-Fossés* to *Roanne* (maximum rate of inclination one in 111), the number of loaded waggons drawn by a single engine may be carried, by exception, to eighty, on condition that the number of brakesmen be increased by one for every two waggons in excess of sixty indicated in the table. "

	MAXIMUM NUMBER OF WAGGONS DRAWN.	
	Train drawn by one engine.	Train drawn by two engines.
Section with gradients of one in 200 at most.....	80	80
do. do. 200 to one in 125	70	80
do. do. 125 100	60	80
do. do. 100 67	50	70
do. do. 67 50	40	50

These figures refer to loaded waggons. For trains containing empty stock, two empty waggons count for one loaded, but without the total real number being able to exceed eighty without special authorization.

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1st. On the sections from *Saint-Étienne* to *Rive-de-Gier*, and from *Saint-Étienne* to *Firminy* (maximum rate of inclination one in 67), on condition of letting down the brake-levers of *one half* at least of the waggons in excess of the numbers given in the table;

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3rd. On the section from *Rive-de-Gier* to *Givors* (maximum rate of inclination one in 143), on condition of letting down the levers of the brakes on *one quarter* at least of the waggons in excess of the number given in the tables.

Further :

4th. On the section from *Saint-Étienne* to *Firminy* (maximum rate of inclination one in 71), the number of loaded waggons composing a goods-train drawn by a single engine may be carried, by exception, to eighty, on condition that the number of brakesmen be increased by one for every five waggons, for the waggons in excess of fifty given in the table;

5th. On the section of *Saint-Germain-des-Fossés* to *Roanne* (maximum rate of inclination one in 111), the number of loaded waggons drawn by a single engine may be carried, by exception, to eighty, on condition that the number of brakesmen be increased by one for every two waggons in excess of sixty indicated in the table. "

insufficiency of these apparatus, one or more waggons should be spragged by pieces *or* wood passed in between the spokes of the same pair of wheels.

" *It is expressly requested, in order to avoid damage to stock, to take out the bars or pieces of wood, thus passed into the wheels before letting the waggons run.* "

" I have the satisfaction of informing you, " wrote on the 3rd of May the traffic manager of the Eastern of France, " that the results of spragging bars have been found good, and that the number of stations where the experiment has been made, fixed first of all at twenty-four, is now eighty-six. The bars have however the disadvantage of sometimes putting the horn-plates out, when the spragged waggons are pushed in station operations, but this inconvenience disappears by degrees, as the use of the bars becomes general, and when the drivers have got into the habit of shunting gently on to the trains, or portions of trains, locked by spragging bars. "

When an engine shunts, in order to take on spragged waggons, the moment for taking out the bar is not always easy to catch, and the notches which form on them, often hinder their being withdrawn.

Thus a ministerial circular (21st of Dec. 1864), acknowledging that spragging cannot be the object of an order, is confined to the recommendation of its use at stations which present conditions of a nature to lead to accidents, " as long as this means of precaution is not supplied by the adoption of completely satisfactory measures. "

In this position, notwithstanding the instructions of some companies, instructions which however have no disciplinary sanction, spragging waggons while standing is little practised on French railways. The bars are often supplied in store, but at the moment when they are wanted, the men have not got them at hand, and they are besides little familiar with the use of them. It is, as always happens in such cases, after some accident that the instructions are brought to mind, and acted on for a certain time. It is right to add that this stimulant occurs very rarely, so that, if little spragging is done, it is that the other means and the supervision exercised at the stations are sufficient within a very little to prevent accidents.

But brakes are the surest and most convenient means for operations with isolated waggons, done either by men or by horses. They facilitate greatly immediate stoppages at precise points, on turntables, for example, and they prevent many little accidents of detail. On the Northern of France, all the goods-waggons which have not a brake with working apparatus, have the lever-brake with a single block. This example should be followed everywhere.

In reproducing the two first paragraphs of the preceding circular of the Eastern of France, an instruction of the Mediterranean system (1st of Nov 1868) has added the following :

" For the execution of what precedes, the store department will deliver to the traffic department pine-bars 8.20 feet long by 0.39 foot in diameter.

" Art. 2. A serious investigation has shown that it might be of use, on lines with steep gradients and in case of the breakage of couplings, to sprag *even while running*, with wooden bars the wheels of waggons, or portions of trains cut off which might be exposed to running down the steep inclines. In effect, in this case, it is better to run the risk of putting out the axles and the guard-plates of the waggons, than to abandon the waggons on the inclines.

" Art. 3. The use of the spragging bar, under these conditions, requires a shorter pattern (pine, 3.28 feet only in length, and 0.33 foot in diameter) handier than the other pattern; but on the other hand, these short bars go obliquely between the guard-plates and the wheels which they infallibly put out of shape; their use under ordinary conditions should be formally prohibited.

" Art. 4. On lines which offer inclines of one in 200 and above, spragging waggons during running may be practised in the case of couplings breaking, in order to prevent waggons or waggons cut off from a train escaping by themselves down the inclines.

" Art. 5. On lines presenting inclines of one in 50 and above, and where spragging may be more frequent and necessary, a bar of 3.28 feet long will be placed in one of the vans at the disposition of the guards, who can make use of it in case of couplings breaking.

" Art. 6. The use of these short bars is prohibited even for trains running on inclines of one in 50 and above, in every other case than that of waggons let go on inclines in consequence of couplings breaking. "

274. We close by a detail with reference to the handling of brakes. A greater or less amount of slackening is not the only precaution required in passing certain temporary works. It is desirable also to avoid, at those points, the increase of tangential efforts and the jerking that would be brought in by the action of the brakes. Hence, for example, the service order (17th of Nov. 1872) of the Eastern of France, relative to a provisional bridge which had been established between the *Charmes* and *Chatel Nomexy* stations :

" The following instructions must be strictly obeyed :

" 1st. Slackening signals will be established on each side of the bridge, at 110 yards off, and on the head of the bridge;

" 2nd. The velocity of the trains must never on the whole length of the temporary bridge, exceed 6 miles an hour;

" 3rd. The tender and waggon brakes must never be tightened up, during the crossing of the bridge, even should the train, from any cause, come on with a higher speed than that prescribed;

" 4th. The trains should never come up to the bridge with velocity slow enough to require the driver to put on steam. "

§ VI. — Continuous brakes. or with transmitting mechanism.

275. We class this category apart, and beyond usual appliances. In effect, in spite of a certain number of fortunate trials and even lengthened and regular applications, the common principle of these systems raises by itself and independently of the mode of application, objections of a certain weight, such as the *time lost* by a long transmission, and the consequence of an injury occurring to the front, paralyzing all the brakes.

These objections ought not however to disencourage investigations; the imperfection and insufficiency of ordinary brakes quite admitted either at high speeds, or on very broken sections, render on the contrary investigation more and more necessary.

The final object to be gained is to place all the means of stopping in the driver's hand. Subsidiarily, and failing that radical solution, it has been long sought, by restricting such action of the driver to the vehicles in front, to divide the rest of the train into lengths of a certain number of vehicles, on each of which a guard may act rapidly and surely.

By multiplying brakes, it is not a question only of increasing the total power of the means of stopping, but also of spreading their action over the whole extent of the train.

Too abrupt a stoppage would produce precisely what the brakes have for object to avoid : shocks more or less violent, and breakages.

To extinguish the *vis viva* of the train, without the application of excessive efforts, as those which meeting with an obstacle would involve, there must be sufficient distance; if not, it is by work of deformation and fractures that the *vis viva* is absorbed.

Effects which may be produced in certain cases by putting abruptly on brakes relatively few. As brakes, under whatever form (counter-steam included at its limit of action), only bring into play the friction due at the most to the weight of the train, and with a low coefficient, dangerous effects have not in general to be feared. All the wheels of a train might be almost always skidded instantaneously, without serious inconvenience to the passengers. It may be otherwise in certain particular circumstances, in the composition of the trains, and of concentration of the means of stopping on some points. The relative velocities of the vehicles may then involve serious disturbances.

Here is a remarkable example : the 11th of April 1872, a goods-train (no. 1113) com-

posed of fifty-six vehicles (380 tons drawn) was running towards *Montélimar* (Drôme); a waggon (K) axle, the 19th of the train, broke; the two wheels, detached, ran on to those of waggons 20 and 21, which they sent off the line. Running through the *Lachamp Condillac* station, the driver warned by the signals to stop made to him there, reversed his steam, whistled for the brakes and stopped immediately; twelve vehicles following the two which had been thrown off were violently pitched outside the rails and overturned; five of them had their buffers deeply interlocked.

The twelve waggons in question were empty, consequently less stable, and the front one was predisposed to rising by its buffers being out of level and above those of the loaded waggon preceding it.

It is probable, however, that this circumstance and the rapidity of the stoppage in front would not have been sufficient to produce effects of such intensity. The facts were so instantaneous that they could not be analyzed with certainty; but the most plausible explanation is that the resistance created by the meeting of the detached wheels determined the breaking of the couplings between waggons 21 and 22; that an interval of greater or less length occurred between the two groups thus separated, and that the very sudden stoppage in front caused a regular collision between them, the effects of which cause acted chiefly on the least stable portion.

If it was thus that matters really took place, the overturning of the twelve waggons was not the consequence, at least direct, of the rapidity of the stoppage, but that of the breakage of the coupling, that is to say of the breakage of an axle.

In the face of an absolute signal to stop, the driver has only one thing to do : to pull up as rapidly as possible, which is what he did. In the case of a coupling breaking, nothing is more dangerous than a very sudden stoppage. But admitting that such existed in this case, it was not observed by those who made the signals; they only noticed something wrong with the waggons which were off the line.

We may remark, on this subject, that when a collision takes place, whatever may be the cause, the effects are often very unforeseen, very capricious. The 16th of July 1871, the goods-train 2110 found the station disc at *Bédarrides* (near *Avignon*) at danger, on account of something being off the line, in the station. It went slowly into the station, and as an extra precaution, a signal was put on at the end of the train. The train following (1898) of 648 tons, went past the disc; and it was only on the sight of the signal behind of 2110, that the driver whistled for the brakes and reversed; but it was too late The three last waggons of the train run into, and the engine and tender of the other train received serious damage. But it was especially on the first waggons of the latter that the effects of the collision were concentrated. Ten of these waggons, pressed on by those behind, were smashed up all together in a heap, which reached to the platform of the tender. At the front of 2110, the men did not even feel a shock, as is easy to comprehend.

276. *Automatic brake.* Nearly twenty years ago, we seemed to be in possession of the solution of the principal problem, if not of the complete solution itself. Whatever may be done, transmission by special mechanism is subject to question. Passing over the complication they introduce into the couplings, in the alterations of the composition of the trains

(rare however with high speed trains), they raise always this objection, that anything wrong happening towards the front of the train, paralyzes at once all the means of stopping. A principle suppressing all special transmission offered by that very fact valuable guarantees.

Such was the *automatic* brake (*). We shall examine it first, but briefly, for the hopes it raised are not yet realized. We do not however believe its principle to be abandoned altogether.

It has long been remarked that the ordinary arrangement of buffing and drawing apparatus of vehicles (II, 166) suits very well for bringing into play the brakes with which they are provided, by the sole fact of the slackening of the head of the train, engine and tender.

As soon as the driver, by means at his disposal, — closing the regulator, engine and tender brakes, counter-steam, — reduces the speed of these vehicles, the train is compressed under the action of the inertia of the vehicles following, the buffer-rods go into their guides, and the work of putting on the brakes, can be taken from this work of *condensation*.

The contrivance employed for this consists in giving to one of the great buffing and drawing springs, freedom to give way under the action of the buffers. In this recoil motion, it acts directly by its middle on the lever of the shaft of the block-cranks. The intensity of the action depends at the same time on the difference of the velocities, due to the slackening at the head of the train, and the driver regulates the slackening as he thinks proper.

The putting of a waggon-brake is determined by the *push* exerted by the waggons which follow it, and the mass of which is acting on its buffers. For a waggon placed towards the end, the brake is put on very slack, because this *push* fails. In order that it may act, it should be followed by two or three waggons at least, free, that is to say without brake, or at least without a brake worked by apparatus.

The omission of this evident condition has often falsified the results observed in trains containing automatic brakes, and the composition of which was known neither to the drivers nor to the guards. The first whistled, as usual, for the brakes; the second, the hinder guard particularly, tightened up his brake, and thus paralyzed the automatic brakes, which, under such conditions were unable to contribute towards the stoppage.

When the driver slackens the head of the train, the automatic action of

(*) See the report addressed to the Minister of Public Works (France) in 1856, by MM. *Piobert, Combes and Couche* (*Annales des Ponts et Chaussées* and *Annales des mines*, 1857).

the brakes acts from behind forwards, and not, as often believed in the contrary way.

We may remark, so as to characterize the properties of the system at once, that it puts not only all the brakes, so to say, into the driver's hands; it is also, in certain cases, absolutely automatic, and acts independently of the driver's will.

Here is an example: on account of repairs being made in the great Vosges tunnel, the traffic was being carried on one single line. The connection being by curves too sharp for the great distance between centres of the *Crampton* engines, one of them, attached to an express went off the line. By the sole fact of the enormous and sudden increase of resistance, its speed was immediately reduced, and the automatic brakes of the train put themselves on with a force proportional to amount of resistance in front.

Perhaps this action prevented a serious accident by developing considerable resistances in the train, and keeping the vehicles in place on the line.

The principle adapts itself readily also, in the case of a coupling breaking in a train mounting an incline, to keeping back the hind part of the train, so separated. It is sufficient for the automatic brakes to be sufficiently numerous, for this portion to include several. As soon as the retrograde movement commences, the guard (always indispensable) at the end, having become the front of the partial train, does like the driver in the direct movement; he tightens his hand-brake, and so creates the relative velocity which puts the automatic brakes present into action.

This character of the system, although very prominent, was misapprehended in a report by Colonel Yolland, inspector of railways to the Board of Trade (*).

This is enough to bring out the fertility of the principle. The difficulties of application will be less easily understood.

The freedom of recoil of the spring which works the brake, cannot be absolute, without restriction. The driver must always be able at need to shunt his train; and as shunting is preceded by stopping, it is necessary that the stopping should have the effect of removing of itself, the freedom of recoil of the spring, under the pressure of the buffers.

(*) He expresses himself thus:

" In the event of the coupling breaking, and carriages running backwards or forwards down an incline, *this brake would be utterly useless by itself:* so that guards with ordinary brakes must still be sent with each train. " Report of the 4th of Sept. only.

This is exact, and on the grounds just pointed out, with respect to the guard at the end of the train only, and he is always necessary, for example, for signals to be rapidly given to the end of the train in case of mishap.

It is entirely in the accomplishment of this last condition that lies the difficulty of the problem; and it is there that the engineers have stranded who first tried to apply a principle so naturally at the same time indicated. In M. *Riener's* system, for example, applied to a stock provided with distinct springs for drawing and buffing, the latter included, for each buffer-rod, two elements: 1st, a spiral spring, elastic with a long travel; 2nd, a *Baillie* spring, much stiffer, acting when the first was compressed. The brake was worked, not by the springs, but by a bracket *f* fixed on the rod between the buffer and the springs. An entirely rigid transmission being inadmissible, a special spiral spring, let in on the rod *t*, divided into two parts, which transmitted the motion to the handle of the brake-shaft, protected the apparatus against the action of the buffer driven violently home, and limited the pressure on the blocks.

In order to withdraw the brake from the action of the buffers, and allow of shunting, M. *Riener* found nothing better than the following expedient: the shaft *a* (Pl. XI, fig. 24), carrying the two levers, one of which L received the pressure of the bracket *f* of the buffer, and the other of which L′, transmitted it to the working-rod, was able to slide on its supports *s*, *s*, arranged in horizontal grooves, and a special lever allowed of its being fixed in the two extreme positions. At the bottom of the travel towards the front, it was placed quite close to the bracket *f*, under the action of which it commenced to turn as soon as the buffer went in. At the end of the travel backwards, at *a′*, it was out of reach of the bracket, and the recoil right back, of the buffer-rod, was effected without the lever of the shaft being touched. After the stoppage, the engine executed a small forward movement, to let out the train and bring back the blocks, the springs and the rods to their normal position; the special lever was worked, an operation having to be done before shunting, for each of the brake-waggons, which was the negation of the automatic property. This was evidently not a solution. To apply a special transmission for skidding the wheels, could not be dreamed of, the property and existence of the principle being precisely the absence of all special transmission.

M. *Guérin's brake.* It was in the hands of M. *Guérin*, civil engineer, that the automatic brake has become not quite practical, but possible.

That engineer would probably have improved his work, if death had not overtaken him in the midst of his researches. This is his solution:

1st. So long as the velocity of the waggon does not exceed a certain limit, 4 or 5 miles an hour (that of station operations, in which shunting occurs continually), the brake does not exist, automatically. If it is provided with

a hand-brake, screw or lever, nothing is changed in the ordinary conditions; the waggon is shunted and stopped as usual.

In the same way, in a train, as long as this limit is not reached, the brakes are not automatic; as it cannot however, even at that speed, be completely deprived of means of stopping, a certain number of its brakes should be arranged to be worked by hand. We have already seen, however, that it must always be so as regards the end-brake, and that generally is sufficient at the low speed in question.

We may at once say, in order to avoid all confusion, that if the automatic faculty only commences at the speed of 4 or 5 miles an hour, this action once brought into play at any greater speed, does not in any way cease when the speed, decreasing, passes below that value. It continues, or can continue up to stopping; it is the driver who regulates its intensity, by acting more or less energetically on the head of the train.

As soon as the train is stopped, a *recall* spring connected by a draw-rod with the large working-spring, tends to bring back the latter to its initial position, an effect aided by the driver giving the engine a forward impulse in order to expand better. It is clear in effect, that the force of the *recall* spring should be limited, seeing that its tension reduces by so much the effort transmitted by the principal spring to the brake-lever.

The return of the two springs to their initial position effects by itself the catching of the movable obstacle which gives at first a fixed point to the spring, and which restores to it afterwards its freedom to return, when the velocity for setting free is reached.

With this, it is easy to follow on the figures the working of the mechanism, which regulates automatically, under the influence of the speed and the stoppages, these alternations of fixity and freedom of the springs.

The draw-hook c carries (Pl. XI, *figs.* 17 and 18) a shoulder e, against which comes, at rest, the arm $o\ m$ of the double cranked lever or fork $m\ o\ p$, jointed to the rod θ, which itself is so with the rod b, hung from the draw-rod t. On the middle of the axle on the same side, a cam k is keyed, in front of which hangs the rod b. When the waggon begins to move, the cam causes increasing impulses and inclinations to the rod. The elements are proportioned, by trying, in such a way that, for the fixed velocity of 4 or 5 miles an hour, the rod b, and with it the cranked lever $m\ o\ p$, is inclined sufficiently for the pin g of the second to pass the projection s, and slide along the latch l. The fork, maintained then in that position, leaves the spring free to go back the whole distance $e\ i$ (fig. 17), more than sufficient for putting on the brakes.

Immediately after the stoppage, the apparatus is in the position shown by figure 18, that is to say with the draw-hook more or less within the small branch of the fork, always raised. The recall spring, and the small forward movement given by the driver, send back towards the outside the whole thing, acting spring, buffers, and draw-rod *t*. But the fork must at the same time fall back into the space, left free again, between the cross-beam and the shoulder of the hook: an effect produced by the passage of the stud τ on the draw-rod, on the continuation *q* of the bolt; the latter rocks, and sets free the fork, which falls back into its place and locks the hook *c*.

277. *Reasons for giving up this brake.* This brake has been the object, not only of numerous trials, but even of lengthened applications. Several hundreds of automatic brakes have run in France, on the Orleans, Eastern, and Northern lines, and on the Northern of Spain where M. *Ricour*, locomotive engineer, saw justly, in this system, a very useful complement of counter-steam for the descent of steep inclines.

Favourably received by many railway engineers who had appreciated all that there was judicious in its principle, and who, without dissimulating the difficulties, looked on them in no way as insurmountable; having scarcely anything against it but a certain ill-will on the part of the brakesmen, who looked upon an automatic apparatus as threatening their occupation, the *Guérin* brake seemed to bring into the working of railways a valuable element of safety.

It has however disappeared almost completely, and from divers causes.

The letting go apparatus, although already improved, did not act with the necessary exactitude and precision. On the other hand, the applications tried, have generally been made with a certain lukewarmness, without consequence, without decision, without bearing.

But the principal cause, that which chiefly shook, then discouraged engineers at first great partisans of the system, is that its application presents special difficulties, precisely in the circumstances where the question of brakes acquired the greatest importance, that is to say on lines of very heavy section.

As was said farther back, the automatic brake is perfectly suitable to the descent of heavy inclines; it presents also (on condition that the waggons provided with the apparatus are numerous enough) very positive advantages with regard to the danger of running backwards on the ascent, in consequence of a coupling breaking. But against this serious danger, there is another very great guarantee, although at times insufficient, that is an engine behind (II, 369). Now, without absolutely excluding each other,

automatic brakes and engine behind, which tends to put them on in all the portion of the train pushed, are incompatible ; in spite of the efforts made, not without success, by M. *Dorré* on the Eastern of France, to reduce the incompatibility, it is incontestable that driving under these conditions, with a train ascending steep gradients, would inflict excessive work and constant apprehensions on the drivers. Restrained by the fear of putting on the brakes, the driver of the hind engine, particularly would dare hardly to push.

A difficulty presented itself sometimes also on the descent. When a driver, leaving a stopping station, is on the point of entering on an incline, he shuts the regulator, before the velocity for setting free the fork is reached; then, the resistance created in the front, presses the buffers one against the other, and the forks against the shoulders of the draw-hooks, so that when the setting free speed is reached, and even exceeded, the friction developed by this *thrust* opposes the letting go of the fork.

Thus, in the instructions it was recommended to the drivers, as soon as the velocity became appreciably accelerated, about 15 miles an hour, to open the regulator for a distance of from 40 to 50 yards, in order to uncompress the train, and insure the letting go of the fork.

But this practice, which consisted in increasing at first the velocity, in order to let the means of stopping come into play, was not very much to the taste of the drivers, who feared, and not without reason, being carried away on the inclines.

The automatic brake could have doubtless given guarantees at least equal to those which an engine behind offers, but always on one condition: that the brakes of the train should be *very numerous*. The natural consequence of the adoption of the principle would have been the application to a very great part, if not to the whole of the effective stock, of simple and economical automatic brakes, in general without apparatus for working by hand, acting even on only one pair of wheels. In that case, if a coupling broke, the putting on of the tail-brake would have been sufficient (as I have had the opportunity of verifying by special experiments) to prevent running backwards. But with brakes relatively small in number (were it very superior to the regulation number), and distributed in an unfavourable manner, that is to say sparse especially towards the tail of the train, the position would certainly be much worse than with the engine behind, which has at the same time the great advantage of straining the couplings less: it was thus necessary on lines with steep gradients, to choose between the engine, and the use of automatic brakes. The choice could not be doubtful, the

more so as the disengaging apparatus did not always act. On the Eastern of France, 43 waggons, separated through a broken coupling at the summit of an incline of one in 100, ran backwards 6 miles, before it was possible to stop them. They included among them waggons with automatic brakes, which did not act; it is true that the position they occupied in the train, is not given; perhaps they were in the hind part of the detached portion.

The always increasing number of heavy gradients constitutes thus, by the fact, a very serious objection, not only to the restricted application of automatic brakes, but also, although with less weight, against its *very wide* application, the consideration of the less strain of the coupling being alone sufficient to warrant the use of the engine behind. It is then chiefly, in reality, for lines with flat gradients that the automatic principle might be the object of fresh investigations, which probably would be fruitless.

M. *Dorré* had already introduced in connection with M. *Lefèvre*, some real improvements, particularly by the suppression of the recall spring, replaced by the large spring, not acting, of the same frame.

278. *Exter's Bavarian brake.* The oldest transmission brake seems to be that (262 and II, 412) which has been at work since 1847, on the Saxo-Bavarian line, at the descent of the *Neuenmarkt*.

One guard works the brakes of a group of three or four waggons, by acting through a system of blocks and return pulleys on the large levers L, kept in place by guides *g*, *g*, and which rise above the *imperiales* (Pl. XIII, *figs.* 18 and 19). A counterweight with a trigger P (*fig.* 19) suspended to a chain wound round the axle T, the contrary way to the cord, allows the bringing on of the blocks, and the commencement of the tightening to be hastened, and the guard completes it afterwards at need, by turning the wheel V. Several times taken off at the request of the brakesmen, then put on again, this counterpoise has been definitively maintained.

Whatever may be the position of the vehicle provided with the working apparatus, the guard can act on the brakes of all the vehicles which precede it, and of those which follow.

Figure 18 shows the arrangement, when the motor vehicle M occupies an intermediate position. The cord, always fixed by one end on the axle T, passes successively over the lever L, the return pulley *p*, the lever L′, returns directly behind, passes over the pulley *q*, over the lever L″ and is fixed at F.

" All that can be complained of in this system, is : the complications involved by the transmitting cords and the return pulleys, and the trouble caused thereby in the formation and breaking up of the trains. The German character, the habits of exactness and punctuality which are generally met with in the lower officials, and the moderate activity

of the traffic, lessen this disadvantage, which in England and in France would render such an arrangement all but inadmissible. As to the efficiency of the apparatus in itself, it is placed beyond doubt, independently of special experiments on a fact, only some weeks after the organization of the working of the gradient. An ascending passenger-train was on the point of reaching the horizontal at *Marktschorgast*, when the coupling of the tender with the van broke. The train, which commenced at once to run rapidly backwards, was soon stopped. "

We have nothing to change in this opinion, which we expressed in 1851 (*). We may add that the mode of transmission by traction would be incompatible with buffing and drawing springs with great travel.

On the *Neuenmarkt* incline (mean, one in 44, maximum one in 40), all the vehicles of the passenger-trains have brakes, which places these trains under conditions of security more favourable than anywhere else, with the same rate of inclination.

279. *Heberlein's brake.* This brake (249) applied to waggons, and combined with the letting go at a distance of the double lever carrying the friction roller, was tried as far back as 1868, on the Northern of Austria. Introduced under that form in Bavaria, in 1872, it is now applied to all the mail-trains on the State line, and seems to give very favourable results, since the staff has become familiar with its use. It has recently attracted the attention of several German managements, and is on trial on the State lines in Hanover, in Saxony and in Würtemberg, on the Lower Silesia and the Mark line, and on a passenger-train of the Berlin *Ceinture* line (**) composed of five or six carriages. It is to the two extreme vehicles (a van and a two-storied carriage) that the brake has been applied, so that the let go cord extends over two or three intermediate carriages.

The general feeling of this insufficiency of ordinary brakes, of the necessity of multiplying the means of stopping in trains without increasing the staff, or, more exactly, to spread these means over a greater number of vehicles, has doubtless a great deal to do with this attempt to return to a system which seemed given up. What is to be found in this brake, is rather the principle itself than the mode of application.

280. *Newall's brake* (Pl. XVI, *figs.* 1 to 10). There is only so far one single example of the mechanical transmissions, by means of which several

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(*) *Influence des progrès des locomotives sur le tracé des chemins de fer. Annales des Mines*, Vth series, vol. I, p. 369, 1852.

(**) *Fortschritte der Technik des deutschen Eisenbahnwesens. Wiesbaden, Kriedel*, 1875, p. 110.

English railways tried for, with more or less success, an increase of safety: this is the English brake of *Newall*, applied on the Northern of France to express trains, and of which the rapidity of action and the power have been greatly increased by M. *Bricogne*, who has substituted a weight (262) for the spring originally employed in the English one. The guard acts on two, or, with a little more time and effort, three vehicles, between which the transmission is established by shafts lying underneath the frames, and connected together by clutches of cruciform section, and with two sockets, which allow of any relative change of position.

In each group, the action is started in a motor-van.

The arrangement of the apparatus is represented exactly: for the motor-van, by figures 1 to 3, and for each of the carriages connected therewith, by figures 4 to 9, which have been engraved from the drawings sent by the chief engineer, M. *Delbecque*. Figure 10 is intended only to give an idea of one group altogether, and it is on the others that the details should be followed.

In the position shown by figures 1 to 3, the counterpoise P, and the lever L articulated with it, working the shaft O of the van blocks, are at the top of their travel. The counterpoise forming a rack, and in gear with the pinion π, keyed on the transmission-shaft a, cannot fall without causing that shaft to turn, which cannot itself turn without involving in this motion the shaft with crank α, α, with which it is solidly connected by the toothed wheel m and the pinion p. But as soon as the handle q (*fig.* 3) is moved to 65°, the obstacle to the rotation disappears, the weight P and the lever L fall, causing the shafts α and a to turn, and the blocks of the van (we occupy ourselves with those first of all) undergo immediately the firs amount of tightening, limited by the slight length of the lever L. The conductor increases it by turning the wheel V (vertical, and consequently with conical gearing); it prolongs thus the rotation of the shafts α and a, and therefore the lowering of the weight P and of the lever L.

As to the carriages, it is clear that the rotation of the shaft a of the van is transmitted, with more or less appreciable delay, to that of the first vehicle, then to that of the second; and the effect of that rotation is equally to press a vertical rack c c (*figs.* 4 to 7) on the extremity of a lever H, jointed with it, and working the blocks.

Each carriage has, like the van, its counterpoise. It is a cast-iron cylinder, only about 33 lbs in weight surrounding the rack c, and like that, contained and guided by the socket M. In spite of its smallness, this weight

has a notable action, on account of the size of the lever H, twice the length of the one of the van.

This distribution of a part of the total motor weight has at the same time an advantage. In case of the breakage of a coupling, and consequently the disjunction of the couplings of the shaft, the brakes of each carriage would receive, *ipse facto*, the amount of tightening corresponding to the fall of the counterpoise, and of the heavy lever solidly connected with it.

One word now as to some essential details.

1st. The shaft a of the van is placed, not along the axis, but on one side to avoid the coupling pieces.

2nd. The carriages have not one shaft only, but two a', a'' (*figs.* 4 to 8), symmetrical relatively to the axis, so that they have never to be turned for the connection, either with the van or with each other. The double shaft is thus a concession made to the requirements, often legitimate, of the traffic departments, which in very heavy working and in certain stations, would have difficulty in finding the time for the necessary operations.

3rd. The two shafts of each carriage should then be conjoined, in order that the movement of rotation of the shaft of the van may be transmitted to to the rack c, whichever may be the one of the two shafts coupled to the van. The connection is effected (*figs.* 5, 7, 8) by a band of hoop iron, crossed over the wheels ρ, ρ, keyed on the two shafts, and which forms a driving-belt of very certain effect.

4th. It will be remarked on figure 4, that the lower lever of the shaft O does not act directly on the rod of the left hand block. The interposed pieces have for sole object, to make up for the extra distance between the axles, carried to 13.12 feet, while allowing the use of the same parts, as were prepared for the previous distance of 11.8 feet.

One group with *Newall's* brake, on the Northern of France, gives for the total pressure on the blocks of the three vehicles acted on by one guard, the following results; we only quote them in the way of example, the elements being capable of considerable variation:

Group formed (fig. 10) of : one van, motor, a first class carriage; a second class carriage; for a total load on the rails of 24,76 tons, or about one half the pressure which, under ordinary conditions, would be necessary to produce skidding, with wooden blocks.

1. *Van*	7.38	9.40 tons	
Load	2.02		
Counterpoise and load of the lever		0.10	
Ratio of that lever to the small levers of the brake		13.58	
Pressure on the blocks (abstraction always made of the inertia of the counterweight, and of the passive resistances) $0.10 \times 13.58 =$		1.358	3.68 tons
Total pressure on the twelve blocks : effort on the wheel multiplied by 354; or for an effort of 44 lbs exerted by the guard on the wheel : 6.97 tons one third of which for each vehicle		2.32	
2. *First class carriage.* Weight	6.40	7.82 tons	
Load 24 passengers	1.42		
Counterpoise, including the load of the lever		0.055	
Ratio of the arms.			
Corresponding pressure on the blocks : 0.054×15		0.812	3.13 tons
Pressure due to the effort of the guard, as above		2.320	
3. *Second class carriage.* Weight		7.53	
Load 40 passengers			
Counterpoise, including the load lever		0.0654	
Ratio of the arms. 15.			
Corresponding pressure on the blocks $0.0654 \times 15 =$		1.073	3.39 tons
Pressure due to the effort exerted by the guard as above		2.32	
Total pressure			10.20 tons

This pressure is slight, but it is rapidly attained ; the van and the first carriage are generally skidded very rapidly, the second more or less rapidly, according as the effort of 44 lbs on the handle is more or less exceeded.

Altogether, the *Newall* brake, such as it is applied to the express trains of the Northern of France, renders undeniable service. If they succeed, as they are trying to do in England and in the United States, in acting on the whole train by means of a simple turning of cocks, that would assuredly be an admirable result, and then the *Newall's* brake will have lived. But, until then, it would not be well to complain of its mechanism, a little superannuated, of course, but of sure effect, and which has long ago shown what it can do. When it is a question of a main function, like that of brakes, care must be taken not to yield to the seductions of very perfect apparatus, excellent when every thing is in order, but the chances of getting out of order increase too often in the very ratio of the amount of perfection.

A decided improvement, derived from the slight effort on the handle p and from the small necessary distances, consists in allowing the driver himself to effect, by a cord under his hand, the letting go of the counterpoise

of the van, and so to act directly on all the brakes of the first group. More certainly still than the whistle, the fall of the counterweight warns, at the same time, the guard, even were he asleep, and he hastens to complete the tightening up. Of course, even in ordinary trains, this addition to the front-van is not neglected, in the means of stoppage placed immediately under the driver's hand.

The efficiency of the disengaging arrangement, even at a distance, has been shown by an application made by M. *Bricogne* to the *imperial train*. The five carriages composing it being comprised (Pl. XI, *fig.* 23) between two groups with *Newall* brakes, each made up of a luggage-van, motor, and two vehicles. By means of a metallic cord, passing over the pulley p and fixed at its two ends to the disengaging handles of the vans, the stoker could bring into action almost immediately the six Newall brakes of this train, 260 feet in length.

M. *Fay's* brake, analogous to *Newall's* brake, and like that much in vogue in England, at a certain period, is now almost given up there. According to the comparative experiments made by the inspectors of the Board of Trade, these two apparatus are equivalent. But the French apparatus has an incontestable superiority.

281. *Clark's brake.* The transmission by the torsion of rigid rods, costly and complicated, is almost obligatory when the efforts to be transmitted are considerable. A chain or a cord may however be substituted for them, but on condition of keeping it always stretched, in spite of the variations in the distances between vehicles. The means which quite naturally presents itself (Pl. XI, *fig.* 19) consists in making it pass, from one vehicle to the other, over three pulleys having for axes the summits of an articulated triangle; the angle ABC opens or closes, according as the waggons separate from or approach each other. This is the means applied long since in *Clark's* brake, on the North London (Pl. XI, *fig.* 20). The tension of the chain is produced, either as shown in figure 20, by hand, by a screw, or, as in *Noseda's* and *Heberlein's* apparatus (249) by a friction roller which the guard presses on the tire of a wheel, or on a disc keyed on to a van-axle, and which causes the winding on of the chain, or better, of two symmetrical chains on an axle. To take the brake off, all that has to be done is to withdraw the roller from the wheel, and in each vehicle the blocks are returned by a counterweight.

In the *Clarke* brake modified by Mr. *Webb*, the friction wheel is pressed on to the disc of the axle by a heavy lever, which can be let go, either

directly, or by the guard in another van, or again, by the driver, by means of a cord brought to his hand. This apparatus, economical enough, but difficult and troublesome to keep up, can only act on a small number of vehicles. It complicates the formation of the trains, and at most is suitable to those the composition of which is hardly varied.

282. *Creamer's brake.* Creamer's brake, much used in the United States, belongs to the category of brakes in which the work of tightening is entirely stored up. The work is accumulated, in each vehicle, by means of a strong spiral spring. A cord passing over all the waggons, and ending on the engine, serves to let go from one to the other, the ratchets which keep the springs tended. The vertical shaft, worked by the spring which imparts to it in unbending, a very rapid movement of rotation, transmits the accumulated work to the blocks. This shaft may be at the same time rendered independent of the spring, and it carries a handle which allows it to be worked by hand.

This apparatus is very defective, or at least very incomplete. It gives all, or nothing. The letting go of the springs once effected, the action cannot be regulated, it goes on to the end. It is a brake for an emergency, and not for regular work; further, the cord which determines more or less surely the putting on of the blocks, is not in a position to take them off again. To put things as they were, each of the apparatus must be acted on directly, and the springs wound up one by one.

If the carrying out is imperfect, the principle, that is to say, of powerful brakes, numerous, and at the immediate disposal of the driver, is seductive. Thus while fully acknowledging the serious objections against the Creamer brake, M. *Petiot* thought well to try it on the Northern of France. The following are the results of experiments on the 11th of Feb. 1863:

Weight of the train drawn	10 carriages with Creamer's brake	56.61 tons
	2 luggage-vans (ordinary do.)	15.48 —
	Engine and tender.	39.96 —
	Gross weight	112.05 tons

The ten Creamer brakes acted alone.

Engine No 36 (*Stephenson*).

Very fine weather. — Rails very dry. — No wind.

POINTS WHERE THE TRIALS took place.		POSITION of the line.	SPEED miles per hour.	DISTANCE run after letting go the springs.	OBSERVATIONS.
From *Paris* to *Pontoise.*	*Saint-Denis*...	Down one in 333	34	1148 feet	8 brakes only put on.
	Enghien.....	Up » 400	32	656 »	The 10 brakes acted.
	Herblay.....	Down » 400	35	820 »	9 brakes put on.
	Pontoise.....	» » 286	45	1299 »	10 do.
From *Pontoise* to *Paris.*	*Herblay*.....	Up » 400	40	689 »	The 10 brakes were put on, but the guard by oversight put his brake on.
	Enghien.....	Down » 286	40	787 »	The 10 brakes were on.
	St-Denis junct.	Horizontal.....	40	820 »	The 10 brakes on. The regulator closed rather tardily.

NOTE. — After acting, about 4 minutes were required to wind up the apparatus by two men.

We bring forward also the results of a comparative trial between this brake, and *Newall's* apparatus, made by means of a special train, including brakes of the two systems, which were put into action alternately.

COMPOSITION OF THE SPECIAL TRAIN.		RATIO
3 carriages with *Newall's* brake (1st group), total wt.	23.95	of the weight brake-able to the total weight.
6 — *Creamer's* — (sole group), —	41.89	
3 — *Newall's* — (2nd group), —	23.34	
12 carriages weight of the vehicles loaded . .	89.18	*Newall's*. . . 38 %
Stephenson engine and tender in running order	37.50	*Creamer's* . . 34 %
Gross weight of the train . . .	124.88	

Note. — The tender-brake was not made use of in the experiments. The tender was counted as mean weight of 12 tons.

	POINTS where the trials took place in kilometres.	SECTION OF THE LINE.	SPEED in miles per hour.	DISTANCE run by the train after letting go the springs.	SYSTEM of brake in action.	OBSERVATIONS.
	From *Paris* to *Pontoise.*			Feet.		
1	kilom. No. 5.	Horizontal.	34	1270	*Creamer.*	All the apparatus acted.
2	» 10.	Down, one in 290.	33	794	*Newall.*	do. do
3	» 20.	Horizontal, between two down gradients of one in 286.	47	1361	*Creamer.*	5 brakes only acted completely. (A cord got off a pawl.)
4	» 27.	Down, one in 284.	47	1312	*Newall.*	All the apparatus acted.
	From *Pontoise* to *Paris.*					
5	kilom. No. 15.	Down, one 263.	35 (*)	1175	*Newall.*	(*) The final speed was greater. This is only a mean.
6	» 10.	» 290.	43	1224	*Creamer.*	5 brakes only acted. (A return pawl was omitted.)
7	» 6.	Horizontal.	35	906	*Creamer.*	All the apparatus acted.

The inequalities of speed and of gradient scarcely permit, out of these few observations, any precise conclusion to be drawn, touching the relative power of the two apparatus experimented on. But what shows up in this table particularly, is the uncertain action of the *Creamer* transmission, and its irregularity even when all are in action. Thus, on a horizontal, the distance run before stopping, was, for very nearly the same speed, 906 feet in one case, and 1270 feet, in the other.

There were, moreover, many imperfections of detail; the blocks hung from the frame, instead of being fitted on longitudinal, gave the carriages pretty sharp jerks. The most of the parts were of insufficient dimensions, the links, clips, and curbs, which served to connect the lines of the disengaging cord, were not solid enough. But the chief drawback (and it is inherent to the principle) is the complication of the work of winding the brakes up again. The *Newall* brake, which can equally be put at the disposal of the driver, winds itself up during running, and this consideration must always insure it the preference.

The brake already cited (II, 206 and 207) of M. *Cochot*, belonging like *Creamer's*, to the category of transmission-brakes by simple unclutching, was simpler; but it had in a greater degree still, the drawback of a troublesome winding up, the skids, which the unclutching dropped in front of the wheels, having to be drawn out and put back in their places. The inferiority of blocks on the rails, to those *on the wheels*, is at the same time beyond all doubt; the first destroy the rails, while in avoiding, as is now endeavoured to be done, going as far as skidding, the second injure the road as little as may be, and not without wearing the tires, but at any rate without altering their circular form.

283. *Compressed-air brakes.* The processes founded on the use of compressed air, are divided into two classes : sometimes the reservoir (or, if required, reservoirs) only is under pressure, and the brakes act when a communication is established between the reservoir and the cylinders, the pistons of which work the blocks. Sometimes the whole thing is under pressure, conduits and pistons on both their faces, and the operation consists in withdrawing one of the faces from the pressure. This second class is distinguished, in England, by the name of *vacuum brake.*

The compressed-air brake is, properly speaking, one which has the effect of applying either the *vis viva* of the train, or a part of the work of gravity, to compress the air in a recipient, whence it can only escape through a more or less contracted opening. Hitherto, this principle has only been

applied to locomotives, which possess the compressing apparatus : cylinders and pistons (*Debergue's* brake, Rigi engine-brake [II, 437]), while the waggons would have to receive apparatus on purpose, in which however there is nothing inadmissible. But although this mode of action seems the most rational, in the attempts made hitherto, the part of compressed air has been restricted to the accumulation and the transmission of the work, by preserving the final organ sanctioned by long habit, that is to say the block pressed against the tire.

The transmissions by the displacement of mechanical organs, appear to have had their day in England, and to have given place, either to compressed air, or to water under pressure, in conduits running the whole length of the train.

In the apparatus established several years since by Mr. *Kyndall* on the London, Chatham and Dover line (Pl. XI, *fig.* 22), three pumps, receiving motion by friction wheels, from the rotation of one of the axles, compress the air in a reservoir placed under the frame; this reservoir is put, at will, in communication with a small pump barrel containing two independent pistons P, P', kept, at rest, almost in contact by a spring, and each of which presses the blocks on to one pair of wheels, as soon as the compressed air is admitted between them. The guard has only to turn a cock, either for putting on, or taking off the blocks. The pressure on the blocks is regulated by the load of a safety-valve, applied to the reservoir.

In *Steel* and *M^c Innes'* brake, the two blocks of each pair of wheels are worked by one piston. The four-wheeled vehicles carry a vertical cylinder at each end on to which is attached an air-reservoir, cast in one piece with it. The upper compartment of each pump barrel is in communication with two conduits, which extend over the whole length of the train, and end in a principal reservoir placed under the foot-plate of the engine, and kept under pressure by a steam pump. At rest, every thing is filled with compressed air. The pistons, equally pressed on both sides, and with the rod below, are kept at the bottom of their stroke by their weight, and by the upper pressure on the section corresponding to their rod. As soon as the driver, by simply turning a cock, lets the air escape from the conduits, and consequently from the upper compartments of the cylinders, the pistons rise, and transmit, by means of a cranked lever and a rod, the effort to the lever of the block-shaft.

Mr. *Westinghouse* puts also the working of the brakes at the complete disposal of the driver, as should be the essential feature of every programme of a transmission-brake.

This brake, from the United States, rapidly spread in that country, and this success has pointed it out to the attention of several European companies. Although many engineers, who would however desire to be convinced, hesitate, to say no more, to look on it as a really practical solution of the problem, it is worth while entering into some details, with respect to an apparatus already sanctioned by serious practice, which recommends itself by its principle, and is doubtless susceptible of further improvements.

The apparatus includes :

1st. On the engine, an air-pump, the piston of which is worked directly by a small special steam piston on the same rod, and an air-reservoir 2 feet in diameter and 3 feet long, laid under the foot-plate; 2nd, two rows of iron tubes 0.75 inch in diameter, placed under the frames of the carriages (Pl. XV, *fig.* 7) and connected together by india-rubber joints; 3rd, under each waggon, a pump-barrel P, 7.75 inches in diameter, with a piston of 1 foot stroke, placed between the two rows of tubes, and connected with each of them by a small branch, so that the cylinder may receive compressed air from either one or both of the tubes. The piston-rod goes out through the end opposite to that where the admission-tube enters, and works the brake with blocks, analogous to the type, so frequent in the United States, represented by figure 20 (Pl. XIII). The effort of the piston is transmitted by the compression of the rods b, b', to the point D of the lever $\alpha\beta$, and thence to the rods 1, 2, 3, 4, and to the blocks.

It is evident that this brake can also be worked by hand, and by one or the other of the handles m, m'; if it is the first that is acting, for example, the traction of the rod 5, applied at α, replaces the *push* applied at o by the piston. The rod (No. 4), which ends at the handle not in action, is thus also pulled on, which is not the case in the first type.

The new parts to be added to the machinery, constitute, in the opinion of many engineers, a serious objection; but these parts accepted, it must be admitted, that the working is as simple as possible, and that the driver cannot complain of purchasing, at the cost of increased work, the increase of safety guaranteed to the train, and of which he himself enjoys the advantage. To work this brake is no more difficult than *whistling for the brakes*, and it is much surer. It is still only a cock to open or shut.

Junction of the tubes. Each end of the tubes has its flexible joint terminated by a metallic portion, and the junction is effected by the insertion of one of these portions into that of the opposite joint (Pl. XIV, *fig.* 10); two springs s, s' pressing against the shoulders e, keep the joints together. In

case of a coupling breaking, the two springs slip, by tending, over the shoulder, the disconnecting is effected without any breakage, and the two valves S, S, which their rods τ, τ, butting one against the other, kept open, immediately close on to their seats, and keep up the pressure, so that the compressed air acts still on the brakes, not only in the front part of the train, but also in the portion detached (the effect can be rendered more energetic by auxiliary reservoirs throughout the train). In the last waggon, with brake, each of the pieces of this joint forms thus, of itself, a plug.

According to a communication from MM. *Ch.* and *F. Fox* to the Institution of Civil Engineers (*), the addition of a special reservoir for each vehicle, has just been adopted by the inventor, and in case of a coupling breaking, the brakes of the portion separated from the engine, act instantaneously, automatically.

The effective pressure in the reservoir being limited to less than 5 atmospheres, the work of the forcing pump is regulated automatically in such a manner as not to exceed that limit; the loss of work is thus avoided, which the machine would be subjected to, if the pressure were only limited by the opening of the valves of the recipient.

In case the air-pump gets out of order, the work stored up in the recipient, is sufficient for two stoppages under ordinary conditions. With the dimensions adopted, an effective pressure of less than 2 atmospheres in the cylinders of the vehicles is amply sufficient.

So far, the mechanism is, if not simple, the principle is opposed to that, at least well combined. The complication of the means may be looked on as a consequence nearly inevitable of the complex nature of the results obtained.

We are unable to say as much for the motive machinery of the air-pump. For want of an axis with a continuous movement of rotation, the distribution of the steam is effected by an apparatus which presents a certain analogy with that of single action Cornish engines. We do not describe it, as the complication of the solution adopted by Mr. *Westinghouse*, seems to us purely gratuitous.

This brake has been tried on some English lines : the Midland, The London and North Western, and the Caledonian.

We borrow from M. *Malézieux, ingénieur en chef des Ponts et Chaussées* (**), the result of two experiments made on the two last lines :

(*) Minutes of proceedings, vol XXXIX. London 1875, page 72.

(**) *Annales des Ponts et Chaussées*, vol. V, 2873, p. 38, *Paris*.

1st. Caledonian railway. *Experiments made, the 21st of May* 1873 *between* Glasgow and Werniss-Bay. 12 *carriages and* 2 *luggage-vans. The wheels acted on by the air-brake carried about* 4/5 of the *gross weight of the train.*

SECTION.	SPEED. at the moment of putting the brake on.	DISTANCE run before stoppage	DURATION of this travel.
	miles an hour.	feet.	seconds.
Horizontal.....	50	817	19
Up, one in 400.....	40	561	17
Down, one in 200.....	58	823	23
do. 125.....	50	800	20
do. 67.....	50	918	23

2nd. London and North Western Railway. *Experiments made between* Staffort and Crewe.

SECTION.	SPEED at the moment of putting on the brake.	DISTANCE run before stoppage.	DURATION of this travel.
	miles an hour.	feet.	seconds.
Horizontal.....	50	895	18
Down gradient (?).....	50	1043	18
do (?).	54	895	18
Horizontal.....	50	777	16
Up gradient (?).....	52	902	16
Down, one in 166.....	52	1043	22
do. 250.....	60	1312	28

These results are satisfactory.

They would have possessed still more interest, if to the action of the brakes that of counter-steam had been joined. We should then have had complete measure of the effect of the means of stoppage. In the preceding experiments the engine only came in by the constant part played by the resistance of its machinery. As to the tender, it had an air-brake like the waggons.

In a trial made in April 1874, on the Midland, it was ascertained, that the putting on of the compressed-air brakes, preceded very appreciably that of reversing the steam by *Kitson's* screw.

This brake works regularly on the Metropolitan District Railway (*London*). It is particularly suitable for lines such as that, when trains follow at very short intervals, and stations are very close.

The promptitude of the stoppages is, in this circumstance, not only a guarantee of safety, but also a condition, *sine qua non*, of the power of the traffic.

But we doubt, in spite of the example of the United States, and in spite of

its success in the official experiments recently made in England, whether the *Westinghouse* brake will establish itself on the great lines, unless perhaps at most for high speed trains running long distances without stopping. Here, the very limited number of the vehicles diminishes the chances of accidental interruption of the transmission; all belonging to the same category of stock, may be provided with the apparatus it requires. We may add however that the dimensions of our vehicles, much smaller than in America and on the Metropolitan, would have the effect of multiplying, with equal useful train-load, the number of vehicles and consequently that of the connections.

It is particularly in the case of ordinary trains, that the objections become serious; the number of vehicles is greater therein, and their composition undergoes more or less changing during the journey. Lastly, as there are no vehicles, even at a low speed, that have not at need (at least on many lines) to be put into these trains, even in front, all the running stock would have to be provided with transmission-tubes. This objection already pointed out (II, 53), on the subject of heating trains by the waste heat, is perhaps of only indifferent bearing in some people's view; but it is, in reality very serious.

Besides, india-rubber connections with their complicated and costly metallic fittings, would sometimes fail through negligence, oversight, sometimes from theft. We quite admit that the communication could easily, notwithstanding every thing, be kept in order in *express* trains; but in the matter of brakes, a solution restricted to that category of trains, would be far too incomplete.

We may own besides that the transmission established with a view to brakes, would also be of use in other ways. It would be easily utilized, as has been done in some trials, for putting the passengers in communication with the head of the train. A small reservoir of compressed air, placed in each compartment, and provided with a cock at the disposal of the passengers, would allow a current of air to be let into the conduit, provided that the brake were not in action just at the same moment, which would work an alarum placed in the van. The guard, whose attention would thus be called, would discover by the appearence of an external signal let go by the same movement of the cock, what compartment has called him. But the same result can be produced by simpler arrangements.

It is clear that the *Westinghouse* brake can also act as a vacuum brake. This variation has been lately introduced into it by the inventor, who seems disposed to adopt it in preference.

284. *Smith's brake.* This is another air-brake, but acting by exhaustion;

cylindrical recipients in elastic fabric, and with the ends strengthened by braces, are filled with air at the atmospheric pressure; the vacuum is made therein by injectors placed on the engine, and by exhaust pumps worked in each brake-van by a friction-clutch on one of the axles. The recipients, in collapsing, transmit by their bottoms, the efforts to the blocks.

285. *Hydraulic brakes.* Water under pressure, so much used in England, for the transmission of mechanical work, could not fail to be applied to the tightening of the blocks.

It is supplied to the conduit running the whole length of the train, and communicating, by means of a small branch, with a cylinder placed under the frame of each vehicle, or by means of a pump worked from one of the van-axles (*Baker's* brake), or by a sort of accumulator installed under the platform of the engine (*Clark's* hydraulic brake). On the Great Eastern, there is a hydraulic cylinder to each block. On the Midland, each cylinder acts on two opposite blocks.

In *Esra Miles'* brake, the conduit separates into two pipes, one ending in the boiler, the other in the tender. At rest, the first communication is closed, the second open, and the pressure on the pistons, nothing. To bring the brakes into action, the driver has only, by turning cocks, to substitute the pressure of the boiler for that of the tender. To take the blocks off, he cuts off communication with the boiler, and springs bring the pistons back.

The project does not appear to have been carried out, notwithstanding its simplicity; it has the drawback of making the limit-power of the brakes depend on the pressure in the boiler.

286. *Brake with electric transmission.* Magnetization and the return to the natural state determined in soft iron, by the passage or the interruption of voltaic currents, and the mechanical effects derived therefrom, make electricity the agent *par excellence* of transmissions. For it, distance and time, do not, so to say, exist. It could not fail to be applied to trains, either for establishing a communication between the passengers and guards, or for putting instantaneously into action all the brakes of a group of waggons. M. *Achard* worked out, some years ago, a complete and ingenious system of electric brake. The tightening of the blocks is determined by the interruption of a continuous current circulating in the train. The objection is thus avoided which rises at first sight against the converse method, that is to say the production of the tightening by the closing of the circuit, any disturbance of the transmission being likely to oppose the passage of the current.

With continuity, an accident of this kind would result in putting the brakes on at the wrong time, a drawback of a certain weight, but much less however than a refusal of the brake to work at the necessary moment. The interruption of the current has besides the effect of only producing a hold, and it is the rotation itself of the axles which produces the prompt, but gradual putting on of the blocks.

In a report of the 5th of May 1866, M. *Combes* said on this subject:

" After long years of study and multiplied trials, M. *Achard* has arrived at a method which has been put to the test on the Eastern of France system, and on the State lines in *Belgium*. The well ascertained result of these trials carried on for more than a year, assure definitively to M. *Achard's* combinations, the first rank among the means proposed and tried hitherto for destroying, in the shortest time and the least space, the speed of running trains. "

We were not able, in 1866, to participate completely in that opinion, and to day even we dare not be so positive. Like *Roland's* mare, M. *Achard's* brake has many qualities, but it had and has still a fault: not that luckily, of the courser of *Charlemagne's* more or less authentic nephew; it is not *dead*, but he is not yet quite *alive*.

When we see electric currents transmit at one stretch mechanical action to distance of several hundred miles, it seems that to act through the length of a train, a few hundred metres at most should only be a trifle.

The consequence is not absolutely exact. Before founding more or less complicated arrangements on the application of electric currents to railway-trains, a mode of transmission of perfectly sure effect should be obtained. The relatively infinitesimal length of the circuits established on trains, withdraws them almost entirely from the chances of perturbations caused by atmospheric electricity; but on the other hand, the transmissions to a great distance are effected by wires, of which the continuity is complete. In trains, the conductibility is only established from one vehicle to the other by simple contact; and even with recourse to pressure springs, it has always something precarious; a little grease, a few grains of sand, and there is an end of the current. The drawback is so serious that it has been proposed to have recourse, as in *Ampère's* apparatus, to metallic points plunging in cups of mercury; but a railway-train is not an apparatus of experimental physics.

The difficulty must not doubtless, be exaggerated; it is less in the nature of things, than in the cooperation of wishes and multifarious cares necessary to insure success. It is often impossible, in railway matters, to draw an exact conclusion from even long continued experiments. If the heads

of departments, taken up with other cares, with little belief in success, or only attaching mediocre importance thereto, keep their distance, and confine themselves to allowing, with a sort of passive compliance, the trials to take their course; if officials of a sufficiently high order are not charged especially to follow them up and render an account of them, the subordinate staff, in general little friendly to novelties, undergoes the influences of the feelings ascertained or believed to be ascertained in the upper regions.

The inventor, devoted to his task as long as he can catch a glimpse of success, that is to say a positive application, becomes discouraged when he sees the aim fleeing before him, and gives up consecrating his whole time to an ungrateful object.

We would not say that this is exactly the history of the electric communication on trains. It has been tried, it must be admitted, with more insistance than many other means, perhaps more practical in reality (for example the pneumatic transmissions of Mr. *Spiller*, of Mr. *Wyer*, etc.); but, in any case, after so many years, the first is still at the same point; in that intermediate state which is neither failure nor success.

Always applied on the Northern of France, it has disappeared on the Eastern of France, and other companies have never tried it.

Is it defective enough to be abandoned, or certain enough to be applied and prescribed everywhere (save, of course, in cases where the end is attained by another process)? At the present date, notwithstanding every thing, we incline towards the second opinion, or at least to an application restricted at first to express trains, for which a means of communication is especially necessary, on account of the long distances run without stoppage, and of the grave consequences which, for them, would be involved by the breakage of axles, tires, springs, partial running off the lines, fires, etc.

Experience proves that, when really wished, the caprices of the transmission are much reduced. It is no longer the time when a train starting from the Eastern of France terminus, with every thing in order, found itself, as early as at *Meaux*, deprived of all communication. On the Northern of France, where the working of the apparatus is frequently tested, the proportion of faults of transmission are estimated, at the present time, at four per cent; a proportion quite to be neglected, and which will probably be improved. There is no reason, besides, why results very nearly as favourable should not be obtained on the other lines, as on the Northern. We say *very nearly*, because the chances of getting out of order increase in a certain measure with the lengths of the journeys, and on that system these lengths are relatively very small.

The application of the system is also facilitated thereon as is remarked by M. *Vidard* (*), by the rule established by the Northern company, to exclude heavy goods from passenger-trains.

If, as the example of the Northern seems to prove, the electric transmission does not merit the mistrust of which it is the object, that would be a very serious argument in favour of the application of M. *Achard's* brake to express trains. As in the compressed-air apparatus, the same transmission would fulfil two functions: signals on the train, working the brakes. The electric communication is simpler, more economical, especially in all that regards the connection from waggon to waggon, and it has the advantage of relieving the engine of the special organs necessitated by the first.

It is a pity that the trials on which M. *Combes* founded, in 1866, his somewhat premature conclusion as to the superiority of the electric brake, should have been given up almost at the very moment when the excellence of the results was proclaimed. It is to be desired that they may be taken up again. Perhaps the Northern, which has been led by experience to accord to the principle of electric transmission a confidence which others still refuse it, will decide to do it, and to endeavour to substitute the electric brake for *Newall's* which we certainly do not wish to abuse, far from it, but which requires an apparatus little in keeping with the progress of practical mechanics.

If we have thought necessary to dwell in a general manner on the principle of the electric brake, and to bring out the considerations which would warrant a fresh study of the question, we shall refrain from describing the ingenious arrangements which characterize M. *Achard's* work. They have not been sanctioned by sufficient experience; and if, as we believe, the electric brake is tried again, it will be perhaps in a form less perfect in its details, but simpler.

Remark as to the communication in trains. It will perhaps be a matter of surprise to see the question, hanging for so long, remain indefinitely stationary. We are always in presence of three modes of transmission: electric, pneumatic, purely mechanical. But when a question is so old, everybody seems as it were tired of it. If an accident happens to call attention anew to it, that does not last, and soon with one accord, it is allowed to slumber again. It would be the time however to come to a decision (although, it must be admitted, there have been no serious accidents in

(*) *Matériel de transport pour voyageurs. Recherche du meilleur système de voiture. Pamphlet* 8vo., *Paris*, 1875, *Baudry*, p. 56.

France for a long time imputable either to the insufficiency of means of stopping, or to the absence of means of communication through the train).

The study of signals in general, and consequently that of communication throughout trains, which is only a particular case thereof, is not included in our programme, and we have only been led to touch thereon, by its intimate connection with the working of brakes at a distance. So we shall only add one observation.

In consequence of a crime committed in a first-class carriage of an express train, the Civil Court of the Seine had a charge of responsibility brought before it, against the company, a charge founded on the electric communication not being at the disposal of the passengers, at least in the compartment, the scene of the crime.

That would be a singular way of encouraging the companies to persever with their trials, to render them responsible for facts, which might have been prevented by the regular working of apparatus purely optional hitherto, and supplementary to the obligatory measures for safety.

The charge ought thus to have been rejected : it was so, in effect, by judgment of the 31st of Dec. 1874.

One of the recitals is in these terms (*) :

.... " Whereas the arrangement of an electric bell apparatus in the carriages is not prescribed by any regulation; that, if the company (whose duty it is, conformably with its interest, to insure as far as lies within its power passengers' safety) has set up apparatus in the *express* trains, it has only done so for the purpose of prolonging trials, *which other companies have already given up, despairing to obtain the regular working of these mechanisms, under the conditions in which they have to work.* "

The underlined passage tends to exaggerate the difficulty of the problem, and to give a sort of judicial corroboration of a pretended impossibility. If some companies have not renewed their trials, suspended during the war, if others have never made any, it is not because they " despaired " of success, it is that they attached a mediocre value thereto. If they had really " despaired ", the example of the Northern would show them to be wrong.

They are hardly more forward, at the present time, in this respect, in England than in France, and they are still less so in Germany. At their last meeting at *Düsseldorf*, in 1874, the engineers of the German Union, while quite agreeing that electric and mechanical transmissions can attain the end, reject them as too complicated and requiring too minute an atten-

tion to be always kept in order. They express the hope that these two solutions may be replaced by another more simple, and they add that hitherto there does not exist one which answers to this *desideratum* (*). There is not even a mention of the transmission by means of a cord, still applied, it is true, on the South Austrian line, but on which no one relies. It is to be met with, however, on various English lines, with some improvements, but rendering it at the same time almost as complicated as the other modes.

287. *State of the question in England.* The supervision of the English railways devolves on the Board of Trade, the Railway Department of which exercises a cautious reserve, which does not exclude consequence and firmness. It observes, and proceeds by the way of representation. Advancing nothing, it never has to draw back.

The Board of Trade long since pointed out to the companies the insufficiency of the means of stopping, and the necessity of a communication throughout the trains. We see in a circular addressed to the companies by Captain Douglas Galton by order of the Board, and dated the 27th of Sept. 1858 :

" My Lords direct me to observe that the amount of break power which is now habi-
" tually supplied to trains, is, in most cases, insufficient to prevent the occurrence of
" accidents.

" There have been thirteen accidents from collisions since the beginning of this year,
" besides a large number of accidents from trains leaving the rails, and from other
" causes, which would have been materially modified in character, if not altogether pre-
" vented, *had the trains to which the accidents occurred, been supplied with an ade-*
" *quate amount of break power.* "

The circular terminated thus :

" My Lords regret that the railway companies have as yet made so little progress in
" adopting a means of communication between the engine-drivers and guards of trains,
" by means of a cord or otherwise, which shall be certain of attracting the immediate
" attention of either the guard or driver, and not be liable to be misunderstood; and my
" Lords trust *that they will no longer delay to provide an efficient means of communi-*
" *cation, as well as a sufficiency of break power for stopping the trains.* "

There was thus only a regret expressed for the past, a hope for the future. Without having the force of a formal legal process, this language ought to have been sufficient to cause the companies to reflect, and to exhance their responsibility in case of accidents. The effect was but indifferent however, and on several occasions the Board of Trade renewed its intreaties in more

(*) *Bulletin annoté* by M. *Lamé-Fleury,* 1875, p. 149.

pressing terms, but with no more success. To this more marked official intervention, was opposed, not only inertness, but replies in which the representatives of the companies discussed and criticized, at times in sharp terms, the inspectors' suggestions.

But the question has now entered on a new phase.

Comparative experiments have just been made in England on the various systems of continuous brakes tried by the various companies. They were carried out on the *Nottingham* branch of the Midland Railway, with the cooperation of the companies, and representatives of the Board of Trade, under the direction of the Royal Commission appointed to study the causes of accidents and their prevention.

In conformity with the programme decided on, the companies which make use of transmission-brakes on their lines, each supplied a complete train, formed of thirteen carriages and two vans.

The companies represented were six in number, and the trains eight in number. The Midland, which employs three types of transmission-brakes, sent them all.

One of the principal companies, the Great Western, kept out of the trials, to which it had nothing to contribute; but intending no doubt to profit by the results.

The official report has not yet been published, but the results of the experiments are known. We give here the figures of two of the most interesting series: In the one (table I), the brakes of the vehicles, including the tender, acted alone. The engine-brake, when there was one, was not worked, and the steam was not reversed.

In the other (table II), the engine-brake, when there was one, acted, if there was none, the steam was reversed right over.

1st. *London and North Western train. Clark and Webb's brake.* Transmission by chain being only admissible for a small number of vehicles, the train was divided into three groups : the two first, of four carriages, and the third of five. Between the first and the second was placed a van provided with two chain windlasses, acting the one on the front group, the other on the hinder group. At the tail of the train was the other van, acting by a chain windlass on the third group. The carriages were six-wheeled and the brake-blocks of cast-iron, applied only on the end wheels.

The van-brakes were put on directly by hand. The tender had six wheels, with a block on each.

2nd. *Caledonian train. Steel and M^c Innes' brake.* Seven of the vehicles, of which were the two vans, had wooden blocks, the eight others wrought-iron.

3rd. *London and Brighton train. Westinghouse (vacuum) brake* (283). Cast-iron

blocks, tender with hand-brake. Single engine, steam-brake, or hand-brake, on the bearing-wheels.

4th. *Great Northern train. Smith's air-brake* (284). This was the heaviest of all the trains: two six-wheeled vans, two four-wheeled carriages, and eleven six-wheeled.

The two vans and one of the carriages had wooden blocks; the others cast-iron blocks.

5th. *Lancashire and Yorkshire train. Fay's mechanical transmission-brake.* Divided into two groups: van with six carriages; van and seven carriages (four-wheeled); wooden blocks.

6th. *Midland. Barker's hydraulic brake* (285). Two four-wheeled vans with a wooden block on each wheel; thirteen four-wheeled carriages with two cast-iron blocks on each wheel.

7th. *Midland. Westinghouse (automatic) brake* (283). The two vans and twelve carriages with a cast-iron block on each wheel; one carriage with two cast-iron blocks on each wheel; the tender, with six wheels, with a brake worked by air or hand.

8th. *Midland. Clark's chain-brake* (281). A part only of the train was provided with brakes.

Table I.

LINES.	TYPE OF BRAKE.	PER centage of the gross train acted on.	SPEED at the moment of the action of the brakes.	Time passed before stopping.	DISTANCE run through before stopping.		OBSERVATIONS.
					actual.	reduced to the velocities of 50 miles an hour.	
		per cent.	miles.	second.	feet.	feet.	
Midland	*Westinghouse* (automatic).	81,1	55,9	22	1020	813	(*a*)
do.	*Clark* (hydraulic)	58,7	54,46	21	1070	902	
Lancashire and Yorkshire	*Fay*	85,0	48,43	24	1017	1079	
Great Northern	*Smith*	87,3	47,50	28	1200	1332	
London and North Western	*Clark* and *Webb* (chain)	62,2	49,50	31	1384	1411	(*b*)
Midland	*Barker* (hydraulic)	81,7	49,50	34	1627	1660	
London and Brighton.	*Westinghouse* (*vacuum*)	81,8	54,46	46 1/2	2000	1854	
Caledonian	*Steel* and *M^c Innes*	81,8	49,50	46 1/2	2136	2179	

(*a*) In all these experiments the rails were dry.

(*b*) In this, the train was cut in two by the breakage of the coupling between the two first groups. It was supposed that the guard of the second had put on his brakes a little sooner than the guard of the first. But the place where a piece of broken hook was found, proved that the train had run 280 yards before the breakage. However that may be, the work of the breakage, taken from the *vis viva* of the train, reduced the distance a little, that is to say the mean distance run by the two portions.

Table II.

LINES.	TYPE OF BRAKE.	PER centage of the gross train acted on.	SPEED at the moment of the action of the brakes.	Time passed before stopping.	DISTANCE run through before stopping.		OBSERVATIONS.
					actual.	reduced to the velocities of 50 miles an hour.	
		per cent.	miles.	second.	feet.	feet.	
Midland.....	*Westinghouse* (automatic).	94,3	52,01	18	840	794	
Lancashire and Yorkshire.....	*Fay, Smith's* brake on the engine and on the tender.	94,2	57,29	28	1401	1007	
Great Northern.....	*Smith* (distribution reversed).....	87,3	45,48	22	922	1112	(*a*)
Lancashire Yorkshire.	*Fay* (distribution reversed).	85,2	45,48	22	928	1122	
London and North Western.....	*Clark* and *Webb*.....	51,7	46,29	22 1/4	978	1132	
Midland.....	*Barker*.....	94,4	49,50	25	1115	1138	
Caledonian.....	*Steel* and *Mc Innes*.....	81,8	49,50	24	1136	1158	
Great Northern.....	*Smith* (distribution reversed).....	87,3	42,76	20	859	1178	(*b*)
London Brighton and South coast.....	*Westinghouse* (*vacuum*)...	94,5	49,50	31	1549	1581	(*c*)

(*a*) The brakes of the hinder portion having been put on a little before the signal, that experiment was recommenced (*b*).
(*c*) The engine steam-brake did not act.

We shall not stop to discuss these figures, which seem to bring out especially the power of the *Westinghouse automatic*, by distinction from the *W. vacuum* brake.

These experiments which only lasted two days, cannot certainly decide the question of the relative value of different systems present; but trials made on such a scale, aud requiring the cooperation of a numerous staff of agents and observers, could with difficulty be continued.

It was already a great deal, however, to bring under the eyes of the engineers of the companies and of the government, the collection of the systems spread over the various lines; and most useful comparisons could not fail to be made, in spite of the short time devoted to the observations.

The important part was not, mereover, that the experiments should be more or less prolonged; but that they should be made, and made through an initiative to which the English are so little accustomed, that of the government. It is a novel spectale in England, to see the department come in so directly, and put the working companies under the necessity of studying in concert with its representatives, the questions which affect safety, and submit instruments, which they put into operation, to official

and practical examination. Nothing like it has been seen in France, that classic country of commissions, fallen somewhat into discredit by the abuse made there of them, by their habit of making too many dissertations round a green cloth, and not enough on the ground.

In that, there is an example for France to follow.

We may be permitted to believe that these experiments instituted with a certain solemnity, will not simply conclude with the declaration that *something should be done*, but that in the state of the question, it is impossible yet to prescribe anything. This inquiry will without doubt have practical consequences, and the companies will accept them, because public opinion is excited by the late accidents. In England, opinion is slow to move, but at the same time it is persistent, and when it is delivered, there is no attempt at resisting it.

§ VII. — **Brakes of the systems of traction by stationary engines.**

288. The stationary engine is only applied at the present time, on gradients of such an inclination that the locomotive could only draw an insignificant load thereon, or even be unable to draw itself up.

It was not always so : the *Liege* inclined planes, for example, were still worked by stationary engines, when steeper inclines had long been worked by locomotives.

While the tangent of the inclination α is inferior to the coefficient f of the adhesion, the retarding force f P cos α corresponding to the skidding of all the wheels of the train, the weight of which is P, is greater than the accelerating force P sin α of gravity; the brakes founded on the friction due to the weight may thus suffice. But the descent being effected without the assistance of the traction cable, and the means of stopping which appertain to the motor, engine and tender wanting, the train drawn should be sufficient in itself and requires more powerful means of stopping. Thence the necessity of a special service of brakes on the gradients of even moderate inclination, such as those of *Liege*, where the traction was done by rope. Six-wheeled brake-waggons, with ballast, and with four skids (264 and Pl. XI, *figs.* 15 and 16) were added to the descending trains, and the return of these waggons was made use of for coupling on of the ascending trains with the endless rope, a coupling effected by means of the griping apparatus already indicated (II, 451, and Pl. XCI, *figs.* 16 and 17).

As to the inclinations superior, and sometimes greatly so, to the angle of friction, the description of the means of stopping, inseparable from that of

the modes of traction, was given farther back (II, chap. XVI). It only remains for us to complete those particulars, as far as regards the funicular method of traction of M. *Agudio*, applied to extreme inclines.

Whenever the adherence, due to the sole weight of the motor (II, 423 and following) is insufficient for the traction, it is also the same for stopping; but if the deficiency is made good, for the traction by horizontal wheels pressing against a central rail, it may be the same thing as regards stopping, by means of blocks tightly clipping that rail. As long as the means of destroying velocity only thus bring the frictions into play, the distance run through before stoppage regulates itself according to the initial velocity, and no excessive efforts are to be feared. MM. *Molinos* and *Pronnier's* brake (II, 446) for example, has the valuable property, that the retaining force, small at first, increases very rapidly with the distance run, and only becomes very great when the velocity has already been much reduced. But when the immense amount of inclination leads to the towing the train along by means of a rack, it is wise to arrange so as to take advantage at need, for stopping, of the points of support offered by the teeth for traction.

This is what has been done at the Rigi, where the driver is able to act directly, by the pistons, on the rotation of the driving-shaft, to reduce it, to suppress it even.

With the rack, the locking of the toothed wheels, is stoppage. But it is clear that if the locking was done when the descending train has acquired, or still possesses a perceptible velocity, breakages would be inevitable, the force necessary to extinguish a given *vis viva*, being inversely proportional to the distance run through, and becoming infinite when that distance is *nil*. At the Rigi, for example, the locking should be done by degrees, under the action of the rapidly increasing resistance applied on the pistons by the increasing throttling of the escape orifice of the air.

Hydraulic brakes of the Mont-Cenis locomotors. (Pl. XV, *figs.* 1 and 2). If, in place of an elastic fluid, the pistons drive before them an incompressible fluid (245), a slow and measured action of the throttling cock is much more indispensable still, its complete closing having then for immediate effect to oppose an absolutely fixed obstacle to the movement of the piston.

The locomotor not having, like the locomotive, working cylinders which can at need act as force pumps, the addition of special apparatus is necessary. Each of the four vertical shafts A, A, has thus been cranked, in order to take the rod B of a non-motor cylinder R, but moved on the contrary by that shaft.

Thence an increase in the weight of the locomotor, an increase which it is desirable to reduce to what is strictly necessary, by reducing as much as possible the pump-barrels π π.....

Now the air, taken at atmospheric pressure, can only be brought to a considerable pressure by its reduction to a small fraction of its initial volume; it thus requires a long stroke of the piston. With an incompressible liquid, this stroke is much reduced, as is also the diameter, because the pressures at the very commencement of the stroke, has a constant value, determined only by the size of the exit-opening through which the liquid is forced to pass. The thickness of the sides diminishes in the same ratio as the diameter, and the dimensions as well as the weights of the movable parts: cranks, rods, pistons are reduced to a minimum. A mechanism very compact, not bulky, and relatively light, is sufficient in that case. Such as they are, the four apparatus of the four shafts weigh nearly 1100 lbs, including the extra-weight of the shafts themselves, cranked and strengthened; and it will be evidently sufficient that one of the two locomotors, applied to each train, should be provided with the supplementary train, the weight of the motor will only be increased, even taking some future modifications of the dimensions, by from 2 to 3 per cent. This is not paying too dear for an increase of guarantee, which is perhaps necessary. It is at the outset, and not after the occurrence of accidents, that all the measures of safety should be brought together, doing away with those afterwards, which can be dispensed with.

The work expended by the fluid on the pistons which they force is employed to compress it, to overcome the friction, and to impart to it the velocity with which it must pass through the opening. Considerable in the case of air, the work of compression is nothing in the case of liquids. But in the apparatus which occupies us, where the same mass of water passes indefinitely from one face of the piston to the other; where every thing, excepting the temperature, is, in that case, found in the same state after each revolution, all the work of the piston is necessarily transformed into heat, which, accumulated in the water and the solid masses in connection therewith, is dissipated chiefly by radiation. In this system, the nature and the degree of compressibility of the substance made use of: gas or liquid, have thus no influence on the total heat disengaged, which is only in definitive, the equivalent of the work abstracted, so to say, by the apparatus. From this point of view, the nature of the intermediate substance, which receives the work to be transformed into heat, is altogether indifferent, precisely as in heat engines, for the intermediate body which receives the heat to be

transformed into work. This nature has influence only on the local elevation of temperature, which is the consequence of the disengagement of heat.

The work to be converted into heat, either for the stoppage of a train having a given speed, or to maintain that speed uniform during the descent on the plane, being known, will give a maximum, and a very exaggerated one, of the final elevation of the temperature of the water and of the pump-barrels, supposing that the latter form an impermeable envelope.

In the Rigi brake, the air being renewed at each stroke of the piston, carries off a part of the heat furnished by the *vis viva* of the train or by the work of gravity.

In locomotives working with counter-steam, heat is taken up in the same way by the steam which escapes through the chimney; but this steam carries off also, as we have seen, heat supplied by the fire (224).

In M. Agudio's brake, in which the liquid is not renewed, it is only through the metallic sides that the heat is dissipated.

The small volume which results from the use of the liquid as intermediate substance, increases the ratio of the external surface to the volume, and is thus favourable to the escape of the accumulated heat.

The great superficial heat of water, renders it at the same time preferable to any other liquid.

For long journeys, it might be necessary, either to renew the water, or to cool the pump-barrels by a small external current of water. At the same time the temperature might be, without disadvantage, pretty high; there are not, in effect, either delicate organs, or grease, and the piston floating in a mass of water, is not exposed to gripe.

The arrangements upon which M. Agudio has decided in concert with the firm of *Cail*, completely realize the programme previously pointed out by M. *Le Bleu* (245). The proof of this brake is not one of the least interesting points of the experiment which at this moment is proceeding, and which ought to pronounce at least on the real value, if not of the Agudio system taken as a whole (*), at least one of the principles constituting it, and which

(*) There is to be found in a work which treats of railways of local interest ([a]), an appreciation which it is difficult to let pass without observation.

" We see ", says the author, " on the subject of the *Agudio* system, that the idea is ingenious, as a means of overcoming the great resistance which the weight of a train would offer on an incline as steep as one in 40, one in 33, one in 25, one in 20, and even beyond. But we repeat, it only appears to us ingenious, and *at the end of the account, from the point of view of economy of*

([a]) *Chemins de fer économiques*, par M. *Opperman*, p. 184.

was without doubt alone applicable under the extreme conditions of section in question. As regards the system itself, let us confine ourselves to stating that the experiment is fully satisfactory. The curves particularly, the number and stiffness of which might still, in spite of the central

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traction-cost, we can never prevent, in order to raise a given weight a given height, the same quantity of motive power being required, and consequently of fuel, however scientific may be the transformations of the motive power."

" It is always the fundamental principle of the transmission of work and of the equivalence of the motive power to the resisting work (in the case of uniform motion), *which is unknown to or ignored by the most part of inventors.*"

If this last lesson be adressed to the inventor of the system of traction, which for nearly twelve years has been exciting so general an interest among engineers, it is more than singular. But let us pass on.

As to the first paragraph, if it means anything, its meaning is that, the *useful* work to be produced being given, it little matters how it is set about; that all the efforts made, in mechanics, to overcome the common enemy, *passive resistances*, in order to increase the useful effect, are unavailing; that for example, in the case of funicular traction, it would be just as well to keep to the cable with direct traction, with the enormous diameter which then be required, and the enormous resistances driving from it.

This manner of looking at and deciding the questions of practical mechanics, has certainly one merit : it is *simple*. But if it is exact, the ideas of the inventors, who give themselves so much trouble for nothing, are not *ingenious* : they are neither more nor less than absurd.

In that case, it is in the value itself of the idea which is done away with, but we see, by arguments little dangerous... at least for it. Elsewhere, this value is fully recognized, but the name of the inventor is changed, without more ceremony.

In an article recently published in a justly approved journal (*), the editor, M. *Maader*, describes the mode of traction by stationary engine, with *locomotor* working on a rack, and he makes a present of the invention, which he seems to think quite recent, to two Swiss engineers, one of whom at least, is of standing enough to require nothing beyond his own (we have not the honour to know the other).

M. *Maader* announces an application in Switzerland soon.

It is quite natural to take advantage, in those parts where patents are not allowed, of the legal *regime* under which one lives. But if there is one thing which should be respected, it is invention, the intellectual property and the just consideration attached thereto, at any rate in default of material advantages, when to an evident authenticity, consecrated by time, by widely circulated periodicals, by public notoriety, in a word, the invention joins an uncontested character of public utility.

By inserting in the *Annales des Ponts et Chaussées* (**), an extract of M. *Maader's* article, the translator, M. *Picard* thougat it " useless to dwell on the *great analogies* which exist " between the system he is describing and M. *Agudio's*.

Now here, according to his translator, what M. *Maader* says (***) :

" In the lines of which we have just spoken, the cable being directly attached to the vehicle, it has to overcome a resistance equal to the component of the weight of that vehicle, parallel to the

(*) Zeitschrift des Oesterreichischen Ingenieurvereins.
(**) Part for March 1875, p. 221.
(***) — p. 224.

rail (II, 463), inspire some fears, are passed over by the cables at the speed of 6.59 feet on the ascent and the descent, with complete facility and steadiness. As to the useful effect, so much was known in this respect, that little was to be learned from the experiment, which has confirmed the previsions.

Train raised : 33 tons gross, of which 21 of waggons.
Work measured on the *Prony*, on the large pulley 464 L. p.

Useful effect { of the turbines. 0.70
of the system. 0.47

This is exactly the figure which we pointed out (II, additions, p. 866) as referring, it is true, to conditions a little different, that is to say to a maximum rate of inclination of one in 2.6 and to a heavier load (58.6 tons).

At *Dusino* the useful effect went up to 0.567 (II, 459).

This is not the moment (we shall return to this point in the additions) to discuss this return foreseen, of 0.47, the relative lowness of which is the consequence of the greatness of inclination, of the length of the plane, of the number and sharpness of the curves. As was desirable for such an experiment, the program carried out, contained the most rigorous conditions, which tended to depreciate the mechanical advantages of the system rather than to bring them out. It was necessary to accept a like inclination, not as a feat, but because in effect, it might in certain cases occur, or at any rate conduce to the most economical solution. The system was to prove, not only that it adapts itself perfectly thereto, save a certain

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rails; whence the necessity of having a very strong cable, and pulleys of large dimensions. In order to remedy this disadvantage, MM. *have thought of a new system of line with funicular traction, in which the cable acts only to cause a pulley to turn fixed on a vehicle.* This pulley works, by means of gearing, a toothed wheel which works a rack fixed in the middle of the line, and so produces the transference of the train. The cable thus supports only an effort equal to a fraction of the component parallel to the rails, of the weight of the train, and it is possible, by the arrangement of the gearing, to reduce this fraction at will. Thus a great advantage is derived, for the cable, being able to have a much smaller section, is so much the more flexible and light. "

It is not then a question of "*great analogies*", but of a perfect identity ; the *locomotor* amplifying the relative speed of the cable, which is the main point studied on a large scale by M. *Agudio*, is rechristened *vehicle*. That is what the *originality* of the "*new system*" comes to.

The error into which M. Maader has fallen, can only be explained by his ignorance of the facts; but this ignorance itself is difficult to understand.

As to the double rack applied by M. *Agudio*, on Mount Cenis, and so happily appropriated to the efforts of traction required by the enormous inclination, it belongs to him neither more or less than the locomotor ; and if it is attempted to dispossess him morally of the second, no more scruple would be had doubtless, at need, for the first.

These few lines will certainly suffice to put the facts on their proper footing, after being so strangely altered in consequence, we would fair believe, of misunterstanding.

reduction, often secondary, of the useful effect on the ascent, but also and especially, on the descent, that it gives every necessary guarantee of safety. These conditions might be very generally improved in the applications. On such sections besides, no doubt the opposition of gravity itself, would be admitted, as on automatic inclined planes in the direct traction, and thus, in a very considerable proportion, the work would be transmitted by the cables, and the installations it requires.

Let us return to the hydraulic brake.

The four pump-barrels π, π, are two and two on the same axis, and with one bottom, back to back. Each of the conduits r, r, is provided with a cock, and these four organs are worked as one, by a handle driving an endless screw.

The expenditure of water is not altogether unimportant, on account of inevitable leaks; these losses ought to be immediately made good; if a vacuum were formed behind the piston, the result would be a shock as soon as it had filled up that space. The supply is insured by a cistern B, placed a little above the cylinders, into which the water should pass by its weigh behind the pistons, by the valves s, s, which open from without inwards. But the air contained in the water, disengaging itself therefrom in the case of a leak, might accumulate in the space so formed and keep the valves shut. This led to closing the cistern, and maintaining therein, by means of a hand-pump, a sufficient pressure to insure the play of the valves. It is evident that this pressure should not be undue, because it reduces by so much, the effective pressure on the pistons.

The addition of a slight proportion of glycerine will at the same time avoid all danger of the water freezing in winter.

As the apparatus should always be ready to work, a clutch for putting in and out of gear, could not be thought of. The four pistons thus worked even on the ascent. But the four cocks being then full open, the increase of resistance arising from that is of no consequence.

The trials commenced on the locomotor provided with these brakes, had to be suspended, on account of leaks taking place at the joints of the cylinders; they are about to be carried on again, after the necessary strengthening.

It is not surprising that these apparatus added afterwards, and not without difficulty to a locomotor not intended for them, should have been found a little weak.

BOOK SIXTH

RESISTANCE OF TRAINS

CHAPTER I.

INDIVIDUAL ESTIMATE OF THE RESISTANCES

289. In order to produce a determinate amount of useful work, the motor engines employed for industrial purposes, have to overcome more or less considerable but nearly constant passive resistances. It is not the same thing in railway industry. This manufacture in full swing of *passenger-miles*, and *ton-miles*, is often subjected to all the atmospheric influences, and the variations of these act not only on the resistances, by the changes of temperature which modify the state of the oil and grease, and by the changes in intensity and direction of the wind, but also on the conditions themselves of the transmission of the work, by the variations of the adhesion.

The resistance of a given train, circulating under certain atmospheric conditions, may thus be very different if these conditions change; from its value corresponding to a mean state of the elements, the power of the engine habitually utilized is deduced, and an excess of available power must meet the accidental increase of resistance.

If this excess is not sufficient to compensate for the increase in question, another compensation comes in of itself, within certain limits, but provided that the state of the rails permits, and besides at the expense of the regularity of the service: this is a reduction in the normal speed, allowing the engine to develop a greater effort of traction (II, 365, 381, 384). For a still greater or too lengthened insufficience of the power, recourse must be had to an auxiliary engine.

Let us make, before entering into the matter, two essential remarks.

1st. The resistance is always expressed in lbs per ton of the weight of the train. Now, every thing else equal, rolling-stock, road, speed, the resistance of a train is not exactly proportional to its weight. It is only so when this weight and the length of the train vary little.

2nd. It is not always known how to take the meaning of the coefficients of resistance which are to be found scattered about here and there. When it is said that the resistance of a train, running at such a speed, is so many lbs per ton, what train is in question? It is the train drawn, or the gross train, that is to say, with the engine included.

And in the second case, how has the resistance been measured? Is it by one of the methods founded on the suspension of the action of the motor, the engine having the regulator closed? Is it by squaring the diagram given by an indicator applied to one of the cylinders? If the regulator is closed, the resistance proper of the organs only comes in by its minimum value. If the regulator is open, the motive power being furnished by the steam, this special resistance is greatly increased.

The resistance referred to the weight will thus be different, according as it is measured:

a. On the train drawn, moving, 1st, alone, in virtue of the speed acquired, or down an incline by the action of gravity; 2nd, under the action of an engine drawing it by the intermedium of a dynamometer;

b. On the gross train, the engine not acting;

c. On the gross train, the engine acting.

The results obtained in these three circumstances are not comparable; and unfortunately the numerical values are often brought forward without the necessary particulars, that is to say, without one knowing if they include the resistance of the organs, and in what measure. In order to avoid all confusion, all uncertainty, it is sufficient, when it is a question of a gross train, to make abstraction of the resistance of the machinery, or in other terms, to express the resistance of the train measured, not on the pistons, but on the driving-axle; this gives the utilized effort, in which the engine only enters as vehicle; and as (at least on a straight line) this resistance differs very little from that of the vehicles, the *coefficient* is the same for the train with or without engine. It is this that we shall examine here.

The indicator diagram gives, not the utilized effort, but the mean effort on the pistons; it is necessary, in order to have the first, to deduct from the second that which corresponds to the resistance of the organs. It is in studying the useful effect of the locomotive that we shall estimate this last.

The necessary *effort* to maintain the uniform velocity of a train on a given

section, may be determined either by the estimate of each of its elements, or in a lump. We shall successively examine these two methods, supposing at first the line to be straight. We shall, after that, seek to measure the increase of resistance due to curves.

Let us take : p the weight of a vehicle, p' that of its load, $\frac{p}{m}$ that of its wheels and axles, R and r the radii of the tire and of the journal. We must estimate: 1st the resistances at the tire; 2nd the resistances due to the sliding of the journals on the bearings; 3rd the resistance of the medium.

§ I. — Resistances at the tires.

290. These arise: 1st, from the compressibility of the bodies in contact: wheels, rails and their supports; 2nd, from inequalities in the road, and especially from the jerks at the joints of the rails (I, 105, 106).

a. Compressibility. Even on the supposition of perfect elasticity, the compressibility of the road would involve a loss of work, and would therefore require on its own account an effort of traction. When the rail would recover its primitive form, the wheel would be no longer there, especially at high speeds, to receive behind equal and contrary impulses to those which it received in front, and the work of the rail would be disseminated, in pure loss, in vibrations.

The effort corresponding to this compression bears, as we know, the improper name of *rolling friction.*

The wheel, of weight π and radius R, being placed at rest on the rail, the middle of the area of impression $m\,n\,p$ (Pl. XV, *fig.* 10) is on the vertical through the centre; if an effort θ be applied to this centre and parallel to the way, increasing up to the moment when strict equilibrium is reached, the point of application of the resultant of the reactions of the rail on the wheel is successively displaced, equilibrium requiring it to be found at each instant on the resultant of the forces π and θ : θ_1 and δ being the values of θ and of AA′ at the moment when equilibrium is about to be disturbed, we have : $\pi\delta = \theta_1 \mathrm{R}$, and $\theta_1 = \frac{\pi\delta}{\mathrm{R}}$.

If δ is constant, θ_1 is inversely proportional to R. This is *Coulomb's* law. But this constancy of δ is only a supposition, and a supposition very little probable. It would be difficult to understand that the length δ should depend only on the nature of bodies, and not on the radius of the cylinder, and on the pressure

According to M. *Dupuit*, δ would be a function of the radius and of the form of $k\sqrt{R}$, k being a constant depending only on the nature of the bodies. The effort of traction $\theta_1 = \frac{\pi k}{\sqrt{R}}$ would then be inversely proportional to the square root of the radius; the values of k would be : on metalling 0.03; — for wood on wood, 0.0011; — for iron on iron 0.0007. But this law is no better established than that of *Coulomb*. Experiments on traction, made chiefly on roads, do not permit an opinion between them, and the oldest one continues to be admitted.

The expression $S = k\sqrt{R}$ may only besides be an empirical formula, true at the very most between certain limits; it gives, in effect, for a plane surface, in contact with a plane $\delta = 1/0$, that is to say that the point of application of the reactions would be at an infinite distance.

For the wheel to turn, θ must either be $< f\pi$, f being the coefficient of friction, or in admitting $\theta_1 = \frac{\pi\delta}{R}$, $\delta < Rf$. If not, there would be sliding and not rotation; if δ were effectively independent of R, sliding would replace rotation as soon as we had $R < \frac{\delta}{f}$.

If, as in *Coulomb's* experiments, the effort θ were applied vertically and tangentially to the cylinder (*fig.* 11), the point A′ would be given by the condition : $\pi \times AA'$ or $\pi\delta = (R - \delta)\,\theta_1 =$ very nearly $R\,\theta$, δ being very small against R; whence $\theta =$ again $\frac{\pi\delta}{R}$.

Then there is no more tangential reaction between the cylinder and the plane, and rotation only is possible.

At all events, as soon as rotation is produced, the greatness of the coefficient of friction of sliding between the matter of the wheel and of the plane is of little consequence, since the friction is not overcome.

In the practical case, of the effort applied parallel to the plane, this friction comes only into play by producing a horizontal reaction, equal and contrary to θ_1; if it were *nil*, there would be no rotation, but a sliding under an infinitesimal effort.

291. *b. Inequalities of the road.* The obstacles with which a road, a metalled one for example, is beset, act in different ways. Either the wheel drives them in, crushes them, or they resist. In the two first cases, work is produced : driving in, or crushing. In the third, there is a shock of the wheel, first against the obstacle over which it rises, then against the road,

on to which it falls down again, and consequently a double loss of *vis viva*. In fact, the three effects may occur all at once.

Power of the wheel. Let us at first remark that if the wheel is placed without velocity against an obstacle, resisting, of the height h (*fig.* 12), the effort necessary to overcome that obstacle is: $t = \sqrt{\frac{2Rh - h^2}{R - h}}$; or h being always very small against R, $t = \sqrt{\frac{2h}{R}}$. The wheel starting from rest gets thus the more easily over the obstacle, with an effort so much the less the greater its diameter. This is expressed by saying that the power of the wheel is inversely proportional to the square root of its radius.

By considerations similar to those set forth in treating of stops (I, 229), but simpler, the loss of *vis viva* is easily determined, which is due to a given obstacle and consequently the increase of mean effort of traction, introduced by obstacles supposed identical and distributed according to a known law.

It is sufficient here to consider a single pair of wheels, each of the slightly projecting obstacles which we regard here acting in the same manner on the two or three pairs of wheels of the same vehicle, which in that case come against the obstacle with very nearly the same horizontal velocity.

As we have seen (I, 229) the total loss of *vis viva* due to the shocks of the wheels against the obstacle, then on to the road, is, representing by $p + p'$ the weight of the vehicle and by K the radius of gyration of the turning parts,

$$\frac{1}{2g}\left(p + p' + \frac{pK^2}{mR^2}\right) V^2 \left[1 - \left(1 - \frac{h}{R}\right)^4\right].$$

If then the obstacles follow each other, as do the joints of the rails, at a constant or mean distance d, the corresponding effort of traction is

$$t_1 = \frac{1}{2gd}\left(p + p' + \frac{pK^2}{mR^2}\right) V^2 \left[1 - \left(1 - \frac{h}{R}\right)^4\right],$$

and the corresponding contingent of the coefficient of traction is

$$\frac{t_1}{p+p'} = \left(1 + \frac{p}{m(p+p')}\right) V^2 \left[1 - \left(1 - \frac{h}{R}\right)^4\right].$$

But the height, the nature and the distribution of the obstacles are so irregular, that each of the resistances applied at the tires cannot be brought explicitly into a formula. They are thus represented by one term, admitting, for want of a better *Coulomb's* law, that is to say, by $\delta\left(\frac{p+p'}{R}\right)$, $\frac{\delta}{R}$ being a numerical coefficient, and δ a length (290)). The evident inexactness of this term, seeing that it includes with resistances, functions of the velocity,

can only be made up for by the mode of observation. By dealing with a railway, an applicable value is at least obtained, in spite of its defective form, at velocities close to those of experience.

It is in this way that M. *Wood* proceeded (*), in a series of observations, which are very old, but must be quoted, for even at the present day we are dependent on them for the special measure of the resistances at the tire.

In order to eliminate the other terms as much as possible, M. *Wood* did not experiment on a waggon, but on a pair of wheels, withdrawn thus from the action of the journals. The *modus operandi* consisted (Pl. XV, *fig.* 13) in placing the pair of wheels at the top of an inclined plane on which it took an accelerated movement; admitting the constancy of the resistances at the tire, and neglecting, at the low speeds of the experiments, the resistance of the air, to which however the moving body offered small hold, the acceleration was constant. The observation of the distance run through during a given time, suffices in that case for giving the coefficient $\frac{\delta}{R}$ or f_1. The load varied by means of axles distributed either as near as possible to, or as far as possible from the centre, or also by means of masses of lead betwen the spokes.

P being the weight of the pair of wheels and its load, turning with it (this weight varied from 600 to 4.480 lbs); $\frac{1}{i}$ the sine of inclination; l the distance run through, V the velocity of translation, and w angular velocity at the end of the time t; $f_1 P$ the required resistance, we have

$$P\left(\frac{1}{i} - f_1\right) l = \frac{1}{2}\frac{P}{g}V^2 + \frac{\omega^2}{2}\frac{PK^2}{gR^2} = \frac{P}{2g}V^2\left(1 + \frac{K^2}{R^2}\right).$$

In order to determine K, M. *Wood* suspended the pair of wheels by the tires to a horizontal axis; he caused this sort of pendulum to oscillate, and counted the number N of oscillations performed during a space of time. T. λ being the length of this simple isochronous pendulum, we have

$$\lambda = R + \frac{K^2}{R}, \text{ et } T = N\alpha\sqrt{\frac{1}{g}\left(R + \frac{K^2}{R}\right)},$$

an equation which gives K. He obtained in this way, for the wheels with spokes, without additional load, $K = R\sqrt{5181}$, a value still admitted to the present day, for wheels with spokes, in spite of some differences of construction.

(*) *Traité des chemins de fer*, pages 115 et suiv.

In order to eliminate V, its value, in uniformly accelerated movement, is substituted for it : the product of the acceleration by the time.

The motor force being $\left(\frac{1}{i}-f_1\right)$, an the mass $\frac{P}{g}$, the acceleration is

$$g\left(\frac{1}{i}-f_1\right), \text{ whence : } V=g\left(\frac{1}{i}-f_1\right)t.$$

Substituting, we have $$f_1=\frac{1}{i}-\frac{2l}{1,54gt^2}.$$

In this way Mr. *Wood* found values comprised between 0.001 and 0.0016. He gave the preference to the smallest, corresponding to the heaviest load, and which on that account seemed to him most likely, the neglected resistance of the air being relatively less in that case.

Mr. *Wood's* figure, obtained with wheels 2.85 feet in diameter, would correspond with wheels of 3.28 feet (1 metre), and admitting *Coulomb's* law to 0.00087. But on the other hand, the velocity in the experiments did not exceed 13 feet, which tends to render the figure of 0.001 too low at high, and even at mean velocities.

Altogether, it is this coefficient which is generally admitted. Uncertain as it may be, perhaps at the present day, it may not be as much in default as might be thought, even for high speeds. We must in fact take into account the much better state of the existing permanent ways, the greater length of the rails, which diminishes the number of joints, and above all the fish-plating, which much reduces the projection of the obstacles. We may add that one pair of wheels, left to itself, is much more subject than a pair of wheels belonging to a vehicle and better still to a train, to deviate on one side and the other, from the mean position on the line, and thus to bring in the shocks of the flanges against the rails. This fact results from the experiments quoted farther on (300, 301) on the movement of vehicles.

It is a pity that so little advantage has been taken of the facilities presented by railways with long and steep inclines, which are at the present time so numerous, to renew at high speeds Mr. *Wood's* simple experiments. It is true that in that case, the action of the air would cease to be so slight as to be neglected; but this correction could be made at the present time with sufficient exactness (297).

One of the series of experiments made by M. *J. Poirée*, towards 1850, on the *Lyons* line, had the object of appreciating the effort of traction due to an increase in the diameter of the wheels, carried, for example, from 2.95 to 3.94 feet. By experimenting, not on inclines, but on horizontals, on a straight line, with the dynamometer, always on isolated pairs of wheels, and at a very low speed (10 feet a second), M. *Poirée* obtained results which

would confirm very nearly M. *Dupuit's* law, that is to say the inverse proportionality to the square root of the radius. The value $f_1 = 0.0009$, found for wheels of 2.95 feet (loaded with 3 tons) would thus go down to 0.00075, with wheels of 3.94 feet. But these trials were not sufficiently numerous to inspire perfect confidence.

§ II. — Effort of traction due to sliding at the journal.

292. The axle may be fixed to the frame, as in the most part of ordinary vehicles, or solidly attached to the wheel, as in railway rolling-stock; for the resistance in question, this is indifferent; the distance run over by the friction for one turn of the wheels is, in the first case, the circumference of the wheel, in the second the circumference of the journal. The latter is a little less, but the difference is very slight when the play is only what it should be. The wheel will turn necessarily; in order for it to slide on the ground, it would be necessary that the moment, relatively to the axis of the axle, of the friction of the journal on the box or on the bearing, should be greater than the moment of the friction of the tire on the ground, which is impossible, the first moment having both a leverage and a coefficient much less; it corresponds at the same time to a smaller load; the sliding is thus brought on to the journal.

It is thus of little consequence, what may be the value of the friction corresponding to the mutual sliding of the substances composing the permanent way and the tire, seeing that this friction does not take place, and that the tangential reaction, less than it, of the two bodies in contact, determines the rotation of the wheel.

Value of the coefficient of friction at the journals. The sliding of one body on another requires a very variable force, according to the pressure, the nature of the substances, the state of the surfaces. This force is, independently of all hypothesis, the tangential component of the reaction of the two bodies, and the angle of friction is the inclination of that reaction to the normal common to the surfaces of contact.

The work of friction produces two effects at the same time : heat, and molecular disintegration; but the disengagement of heat may be so slight and the wear of the substances, acting on each other, so slow, that very probably these effects do not represent the whole amount of work absorbed by the friction; one portion is disseminated in vibratory movements.

There is besides in sliding, an effect analogous to that which takes place in rolling, that is to say, the impress of one of the substances in the other, forming a sort of flange which has to be at each moment compressed by the

first. However, without discussing the nature of friction, and whether it is composed or not of one portion constant, and another depending on the state of the surfaces, the essential is that, as proved by experience, its minimum intensity corresponds, every thing else similar, to the minimum of heating.

If the journals of railway rolling-stock are under less favourable conditions than the spindles of machinery (II, 75), this inferiority is greatly reduced for passenger-carriages. It has long been admitted in industrial matters, that the coefficient of friction between well finished metallic surfaces, with continuous lubrication, hardly goes below 0.05 or 0.040. No doubt that, on railways, it reaches and even exceeds accidentally that value; but neither is there any doubt that it is at the present time much less in general, even for goods-stock.

It has long been endeavoured, and by Mr. *Wood* himself, to do for the friction of the journal, what he had done for the resistance of the tire, that is to say, to measure it when set free from all other. Values obtained at first by difference, that is to say by subtracting from the total resistance of a waggon, the resistance at the tire estimated at $\frac{1}{1000}$ of the total weight, varied from one to two $\left(\text{from } \frac{1}{10} \text{ to } \frac{1}{23.2}\right)$ (*). In some much earlier experiments made by *Southern*, that value fell to $\frac{1}{40}$. A second series of observations made by Mr. *Wood*, on a waggon constructed on purpose and with great care, gave him, always by difference and admitting $f_1 = 0.001$, $f = \frac{1}{60}$ or 0.017, a value confirmed since by experiments made with the greatest attention (**). These discrepancies determined Mr. Wood to have recourse to direct observation. His apparatus came, in principle, to that since applied for testing oils (II, 75). An axle placed with its journals in two bearings, at 30 feet above the ground, and more or less loaded by leaden rings, received a velocity of rotation from the fall of a weight attached to a cord wound on a pulley keyed on the middle of the axle (***). As soon as the weight, arrived at the bottom of its travel, and its velocity destroyed by its shock on the ground, ceased to stretch the cord, the latter left the pulley of itself, and the axle continued its movement until its *vis viva* was extinguished by the work of the friction of the journals, and also, to a small

(*) Wood, page 118.
(**) Ibid., page 119.
(***) Ibid., page 128.

extent, by the resistance of the air and vibrations. By neglecting these, it was sufficient to count the number of turns, until the axle stopped, in order to get the coefficient f.

Mr. *Wood's* text does not state whether any corrections, the omission of which would exaggerate the value of f, were made.

He has not given in his work the values thus obtained by him. He confines himself to deducing from his observations as a whole, this conclusion, for which in appearance, there is little ground, that for f, 0.05 (*) can be admitted, that is to say, the value which still figures at the present day, in most engineers' pocket-books.

He adds that this value supposes a pressure (mean) of 100 lbs on the square inch, and increases for loads greater or less.

293. *Values found in Germany*. Experiments made later on in Germany, have given values in general much smaller.

1st. M. *Pauli*, experimenting in 1847 with bearings of different nature of the Bavarian stock, and under variable loads, found for f, from 0.0089 to 0.13. The load being increased by 36 per cent, the coefficient doubled (**).

2nd. M. *Kirchweger's experiments*. The most complete series of experiments is that made in 1861-1862 by this engineer, in the *Hanover* work-shops.

His apparatus is shown by figures 11 to 13, Pl. XIV. A pair of wheels R, R, fitted on, is placed on two pedestals L, L', which take the journals; on one of them is placed an ordinary axle-box G, with its bearing and without the lower cover; it supports a balance-beam F, F, to which are suspended two scales p, p, taking weights which constitute, with that of the beam, the load on the journal.

The beam being in equilibrium, if by means of a pulley C, keyed on the axle, and of a band driven by a steam-engine, the axle is made to turn, equilibrium is disturbed, the friction of the journal on the bearing tending to draw over the beam: weights are successively added to the scale which rises, until it becomes horizontal, or rather until it oscillates round a mean horizontal position. It is thus an experiment with a *Prony* brake. The friction measured, is developed exactly under the conditions of working, and the nature of the bearing, and that of the grease or oil, are varied as desired, the velocity of rotation, and the load of the beam, represent the suspension-spring which loads the axle-box.

Q being the total weight of the beam, balanced before the rotation of the axle, q the additional weight which maintains equilibrium during the mo-

(*) Wood, page 132.
(**) *Handbuch für specielle Eisenbahntechnik*, etc., vol. II, p. 141.

tion, l its leverage, r the radius of the journal, f the required coefficient

$$q\,l = f\,(Q + q)\,r.$$

If the rotation is reversed, q_1 being the additional weight and l' its leverage, we have similarly

$$q_1 l' = f\,(Q + q_1)\,r$$

whence

$$f = \frac{q\,l + q_1\,l'}{(2\,Q + q + q_1)\,r}.$$

If $l = l'$ we have, that length being at the same time great enough, and consequently $q + q$, very small against $2Q$

$$f = \frac{(q + q_1)\,l}{2Qr}.$$

It was tried, in the Lyons Railway workshops, to apply the same method of observation, but without success. As soon as the velocity of rotation reached a limit far below that in service, it became impossible to keep the lever in a mean position of equilibrium. Previous trials made in 1847 and 1848, at the State waggon building-shops at *Nuremberg*, had led to this method of experimenting being given up, and to the substitution of a special dynamometer in place of it. In his note of the 3rd of Sept. 1862, M. *Kirchweger* however makes no allusion to any difficulties of this kind, from which he escaped, doubtless by a better installation of the apparatus, and especially by a greater mass given to the supports.

The load and the speed varied so as to include the whole practical range, that is to say between 1 and 4 tons, and up to 180 turns per minute. Some experiments were also made at a very low speed, 10 turns; the movement was in that case done by hand. Experiments were made on bearings of different alloys, on greases, on oils, and at different periods of the year, in order to ascertain the influence of the temperature, which varied from 23° to 68° (F).

Bearings.

1st. Bronze of the *Cologne* and *Minden* line: Copper, 20; Tin 2; Zinc, 1; Lead, 1,

2nd. Antifriction metal, prepared by melting: Tin, 59; Antimony, 13; Copper, 95. casting in thin plates, adding to these 81.5 parts 88.5 parts of Tin, remelting and casting into bearings.

3rd. Alloy of Antimony, 85; and Lead, 15.

Greases: Tallow, *Schroeder's* grease.

Oils: rape, olive.

Journals	Iron	3.5 × 5.51 inches.
	Steel.	2.76 × 5.51 —

Abstract of the results.

I. *Rape oil.*

Bearings of white metal: f varied from 0.009 to 0.0099.

do. bronze: $f = 0.0141$, or 50 per cent more.

f is independent of the load and of the speed.

II. *Grease.* With heavy loads, f is the same as for oil; but the load decreasing, f commences to increase at a very low value of the load.

f is independent of the speed.

Between the limits of 23° and 68° (F), the temperature has no influence on the values of f.

The table includes three observations of the friction at starting, according to which it would be about ten times what it is during running. It does not appear to be admissible that the indispensable precautions, easely taken in this case, for preventing the results being falsified by inertia, were neglected. If the friction at starting seems great, the very fact of its existence, although it may appear in no way proved, is nothing which should cause surprise (II, 211); a lengthened rest may, especially under a heavy load, squeeze out the lubricating material by degrees. If it be so, this effect should be more marked, and consequently the friction at starting, greater still with the oil, than with the grease on which M. *Kirchweger* experimented.

Of course we make abstraction of the influence of the temperature on the physical state of the fatty substance. In winter, the grease may acquire, after a lengthened rest, a consistency which greatly increases the friction at starting.

Experiments of MM. Bokelberg and Wellkner. Nearly at the same time as M. *Kirchweger*, MM. *Bokelberg* and *Wellkner*, made at the *Göttingen* workshops, experiments by means of an analogous apparatus (Pl. XIV, *figs.* 14 to 16). The axle had three journals; two f, f', rested on two ordinary pedestals, and the third, external, took the axle-box and its load, applied by means of the plate II to the double lever L, itself suspended to the frame $m\,n$. The movement was given by a strap and pulley C.

Journals { Diameters. . . . . 4.49 | 3.5 | 2.76 inches.
Lengths. . . . . 8.50 | 7.52 | 5.51 —

Loads from 1.25 to 5 tons.

Velocities : corresponding to a translation of from 11 to 38 miles.

Abstract of the results.

Minimum value of f: 0.0028 (small load, and low speed 11 miles).
Maximum — 0.013 (heavy load, and high speed 61 miles).

Instead of being independent of the load and the speed, the coefficient would thus increase with the one and the other, with the first especially. On the other hand, instead of giving, every thing else the same, the greatest friction, bronze would give on the contrary the lowest coefficient.

The accord between the two series is thus very poor. But they agree however on one essential point, the constant and often exceeding great

inferiority of these values, relatively to the admitted figure of 0.05 ; a consequence which the trials made at Nuremberg had also led to, and the results of which do not appear to have been published ; perhaps they did not inspire much confidence, so different were they from the figures ordinarily admitted. The consequence in question is not however the only one coming out of these trials, which has been since confirmed, at least in a general manner; such are also the advantage of large rubbing surfaces and the non-proportionality of the friction to the pressure.

The alloy with the minimum of friction was, according to the same experiments

Tin.	90 p. 100
Copper	2 —
Antimony.	8 —
	100 —

but on condition of employing the tin very pure ; the ordinary metal of commerce gave on the contrary very bad results.

M. *Vuillemin* and his collaborators give the following values for f (*) :

Waggon. . . .	with grease	$f = 0.032$
	— oil	$f = 0.010$

But they were obtained, the first especially, in a very indirect manner:

1st. The total resistance of a waggon, running with oil and weighing 5.5 tons, was found, at a very low speed (3 miles an hour at the outside) to be 24-25 lbs. Admitting Mr. *Wood's* figure for rolling ($\frac{1}{1000}$), the wheels and axles weighing 1.6 tons, which gives for the load on the journals 3.9 tons, and the ratio between the radii of the journal and the tire being 0.075, we have

$$24.25 = 2240\,(3.9 \times 0.075 \times f + 5.5 \times 0.001) \text{ whence } f = 0.018.$$

2nd. Previous experiments made on the same line having shown that with grease, the coefficient of traction is greater than with oil, in the ratio of 1.35 : 1, it was admitted that with grease, the resistance would have been 32.8 lbs instead of 24.25 lbs, whence $f = 0.032$.

The same experimenters found (**) :

1st For a tender (grease) at the speed of 15 to 18 miles :		$f = 0.043$
And 2nd — an engine (oil)	—	$f = 0.053$

From the comparison of the two values relative to oil : 0.019 for waggons and 0.053 for engines, and from the respective surfaces of contact, or better speaking, from the longitudinal sections of the journals : 29 and 100

(*) *De la résistance des trains*, etc., p. 56.
(**) *De la résistance des trains*, etc., p. 37.

square inches, the authors concluded (*) « that there is always advantage in reducing the rubbing surface to a minimum. » A conclusion which accords neither with the general idea, nor with observation. What is advantageous to reduce to a minimum, is not the « surface of contact », that is to say the longitudinal section of the journal, but the diameter, because then the distance run through by the friction is proportionately reduced. The surface, on the contrary, should be large enough for the load per unit to be not excessive, as that would cause the oil to be expelled and griping to take place. Thus it is necessary, in reducing the diameter as much as the resistance of the journal will permit, to give it such a length as will spread the load over a sufficient surface; and for external bearings, as we have already remarked (II, 81) the length reacts itself on the diameter, which ought to increase therewith. This necessity of limiting the pressure per unit of surface, in order to lower the coefficient of friction, is beyond all question, and there is much more to fear from being in default than in excess. We do not hesitate to attribute for a good deal, the raising of the figure as regards the engine on the Eastern of France, not to the exaggeration of the surface of contact, but on the contrary, to its insufficiency that is to say to want of length in the journals. Their surface is greater for the engine than for the waggon in the ratio: 2.4 to 1; but the ratio of the loads is greater still, so that the load per unit is greater for the engine, and that is sufficient for the coefficient to be so, but not however in the ratio of 0.35 to 0.019; all the more that the engine, by the minute and constant attention of which it is the object, is under more favourable conditions than the waggons, and even than the carriages, which ought generally to compensate for the influence of a certain excess of specific load.

It is necessary at the same time, as need scarcely be said, in the estimate of that load, if it be a question of a driving-wheel, to take into account its part in the effort of traction. By neglecting this component, the coefficient f would be exaggerated, and the more so, at equal speed, the heavier the train.

If the results which precede prove the exaggeration of the coefficient 0.05 (a fact confirmed by other conclusive observations [305]), they present too much divergence for a value to be deducible from them, to substitute for that figure. It is better worth while to continue to admit it provisionally, but as a maximum very rarely reached, and not losing sight of the fact that it tends to cause an exaggerated value to be attributed to the work developed by an engine drawing a given train, particularly on a horizontal.

f may without doubt rises much higher still, if a box gets empty and sand

(*) *De la résistance des trains*, etc., page 39.

gets in; but that sort of thing is a regular accident, which may go as far as cutting of the journal. The thing is to prevent such occurring, to prevent the boxes from heating, and not to know how far the resistance may go in abnormal circumstances.

294. *Portion of the effort of traction due to the friction on the journals.* Les us now try to discover the portion of the effort of traction arising from the friction on the journals.

The wheel may be loose on its axle, as in the vehicles on ordinary roads, or solidly attached to it, as in railway rolling-stock, which is, however, indifferent from the point of view of the effort sought.

Let us suppose for example, the first case (Pl. XV, *fig.* 14).

Before the application of the effort of traction, the generating line of contact takes successively the positions A′, A″ A‴.... which are determined by the condition that the journal may be in equilibrium on the corresponding element of the box by the action of the forces P and τ, P and τ', P and τ''.... This displacement reaches its limit when τ reaches its limit t, for which the rotation commences; the inclination α to the vertical, of the radius terminating on the generating line of contact, is thus determined by the condition

$$P \sin \alpha - t \cos \alpha = f (P \cos \alpha + t \sin \alpha),$$

whence

$$\operatorname{tang} \alpha = \frac{t + fP}{P - ft}$$

the angle of the resultant of the forces P and t with the vertical being

$$\operatorname{tang} \alpha' = \frac{t}{P}, \ \alpha \text{ is } > \alpha',$$

The radius ending on the line of contact is thus above that resultant, and the angle of the two radii is

$$\operatorname{tang} \beta = \frac{\dfrac{t + fP}{P - ft} - \dfrac{t}{P}}{1 + \dfrac{t + fP}{P - ft} \dfrac{t}{P}} = f$$

The pressure to which the friction is due this

$$\sqrt{P^2 + t^2} \cos \beta = \sqrt{P^2 + t^2} \frac{1}{\sqrt{1 + f^2}},$$

and we have for one turn of wheel for example.

$$t \times 2\pi R = f \sqrt{P^2 + t^2} \frac{1}{\sqrt{1 + f^2}} \cdot 2\pi r,$$

whence

$$t = \frac{fPr}{\sqrt{R^2 + f^2 (R^2 - r^2)}},$$

or, as f^2 can be neglected against 1, $t = fP \dfrac{r}{R}$, a value which can be put

immediately, when the displacement of the generating line of contact is not taken into account; a supposition rationally impossible, but which involves only a small error in the value of f. We thus admit it, extending it, which is permitted within the same limits of approximation, to the fixed bearings and turning axles of railway rolling-stock.

§ III. — Resistance of the air.

295. The resistance which a fluid at rest opposes to the passage of a moving body, depends on the relative velocity, on the density of the fluid, on the projection of the body on a plan perpendicular to the direction of its movement, on its form and proportions.

The influence of the velocity V may be represented by a function of the form of $\alpha V + \beta V^2 + \gamma V^5$. Like the old experiments of *Newton*, those of MM. *Piobert*, *Morin* and *Didion* made at *Metz* in 1835-36, on thin plates in movement in air at rest, pointed out the existence of a term independent of the velocity. This constant, which in liquids represents the viscosity, is little explainable with regard to gases; it may however be neglected, even at the lowest railway speeds. Within the limits which concern these latter, the proportionality of the resistance to the square of the velocity is sufficiently exact. For very high speeds, such as those of projectiles, the resistance increases more rapidly than the square of the velocity.

It is besides proportional to the density of the fluid; as to the influence of the surface striking against the air, if, for greater simplicity, we consider a prism animated in air at rest, with a uniform velocity parallel to its edges, it seems that the resistance ought to be proportional to the base S of the prism. *Borda's* experiments, had, however, led to a result somewhat different, at least in appearance; the resistance increased, not as S, but as $S^{1,1}$: a paradox which, as M. *Thibault* showed, arose from the mode of observation adopted. Borda employed a circular motion, much more convenient for the installation than a rectilinear movement. He experimented on thin planes, turning with different angular velocities round an axis O (Pl. XV, *fig.* 16). Now the anomaly which persists as long as OA remains constant for the divers values of AB, disappears as soon as the two values are made to vary simultaneously, in such a way that the ratio $\frac{OB}{OA}$, and consequently the ratio of the extreme velocities of the moving plane, remains constant. The proportionality of the resistances to the areas is

thus exact. Now, in rectilinear movement, the condition enunciated is fulfilled; it is the particular case where the ratio = 1.

The action of a fixed obstacle on the air in motion, appears however to extend beyond the limits of the first. Mr. *D. K. Clark* quotes this fact (*) that, during the greatest storms and when the wind takes the broadside of the great Britannia bridge over the Menai Straits, one can hold on without danger on the top of the girders. The velocity of the wind is thus greatly deadened for a certain distance above and below. The threads of air, checked and deviated directly, act themselves, by lateral communication, on the upper and lower ones.

In spite of the importance of the air either as resistance to movement, or as motor in navigation, and in windmills, we are not yet in possession of a well established expression of the pressure exerted by the air even in the most simple particular case : that of a thin plane.

M. *Poncelet* gives (**) $p = 0.088\ V^2$, V being the velocity of the wind in metres per second, and p the pressure in kilogrammes per square metres.

According to M. *Levy* (***), $p = 0.113\ V^2$.

Mr. *Debauve* (****), gives the following figures :

	V	p
Light breeze	6.56 feet.	0.11 lbs.
Wind good for mills	22.97 »	1.31 »
Impetuous wind	66.62 »	10 88 »
Tempest	119.00 »	35 44 »
Hurricane	150.30 »	55.60 »

And M. *Ledieu* (*****) these, admitted according to him, in the Navy.

	V	p
Wind scarcely perceptible	1.64 feet.	0.004 lbs.
Light breeze	6.56 »	0.011 »
Stiff breeze	32 81 »	2.62 »
Very fresh	66.62 »	10.20 »
Gust	88.58 »	27.43 »
Hurricane which overturns buildings	147.64 »	43.25 »

(*) *Railway Machinery*. Page 130.

(**) *Mémoire sur les couvertures en zinc. Mémorial du génie*, No 13, p. 283.

(***) *Statique graphique*, 1874, page 166.

(****) *Manuel de l'ingénieur des Ponts et Chaussées*. Mécanique. 1873, p. 289.

(*****) *Traité des machines marines* vol. 1st, page 143.

296. *Influence of the length of the prism.* — If for a thin plane moved in the air at rest, prisms of the same base and increasing lengths be substituted, experiment shows that the resistances, diminished at first increase afterwards, slowly however, and that the minimum corresponds to a length equal to $3c$, e being the side of the square equivalent to the base. This is very nearly the proportion for the body of a four wheeled passenger carriage.

This influence of the length, favourable up to a certain limit, contrary beyond, is conceivable. The statical pressure of the medium is not reestablished immediately behind the medium. There is thus on the hind face a partial vacuum, a *non-pressure* which adds to the pressure on the front face.

Every thing else the same, besides, the *non-pressure* is a maximum for a plane without thickness; the length of the prism increasing, the gaseous threads, less deviated, approximating more to the parallelism of the prism, do not disturb the mass of air in the same degree behind the moving body, and the non-pressure diminishes. But at the same time, with the length the friction of the air against the sides of the prism increases; the first effect at the commencement overcomes the second, but only up to a certain limit of length, beyond which the one ceases to increase, while the other always increases.

k being a coefficient variable with the ratio in question, it is ordinarily admitted, with Mr. *de Pambour*, $p = 0.0625\ S^1\ V^2\ k$ (S being the surface struck against in square metres), and for a thin plane, $k = 1.43$, maximum value. It is this which makes the above value of p coincide with that of M. *Poncelet*: $p = 0.088\ SV^2$.

For a prism having the ordinary proportions of a waggon, $K = 1.15$ and $p = 0.072\ SV^2$; and V being expressed no longer in metres per second, but in kilometres per hour, $p = 0.005\ SV^2$. We have altogether for a waggon:

$$t = 0.001\,(p+p') + 0.05\,\frac{r}{R}\left(p+p'-\frac{p}{m}\right) + 0.005\ SV^2.$$

297. *Valuation of* S *for a waggon.* — S includes three elements: 1st, the plane surface of the body, of the frame and of the front axle-box; 2nd, curved surfaces relatively small: those of the first pair of wheels; 3rd, masked surfaces: those of the axle-boxes, wheels and axles of the second pair.

According to the theory admitted before *Borda's* experiments, the resistance encountered by a sphere (or a hemisphere) would be half that of the great circle. But this theory only accorded with the observations in what con-

cerned the proportionality of the resistance to the square of the velocity. On other points it was also very discrepant, and was good for nothing but to lead into error (*). A rough approximation is thas put up with, which consists in admitting that a cylindrical surface is equivalent to the one half of its projection on a plan perpendicular to the direction of the movement. This doubtless lays too much to the curvature; thus, M. *Fresnel* admitted that, with equality of longitudinal section, the pressure of the wind was 50 per cent greater for a pyramidal chimney than for a conical one. But the curved surfaces being very accessory in railway-trains, a slight error in detail matters little, especially in the presence of the incertitude which prevails on the essential points.

The second pair of wheels, although masked by the first, is separated therefrom by too great a distance to completely escape from the action of the air, which can only be reduced more or less. By travelling along together two thin squares which exactly covered each other, M. *Thibault* ascertained that their distance apart being equal to the side of the square, the pressure on the second is 0.7 of the pressure on the first; whence it is allowable to conclude, the internal between two pairs of wheels being almost always relatively greater, that the second is impinged against with the same intensity as the first.

On account of the curved portions, the two pairs are thus equivalent to the plane section of a single pair, and the axle-boxes alone should be reckoned integrally in order to form S.

For a passenger-carriage for example, we have

		sq. ft.	sq. ft.
S =	Body 6.56×8.53	55.98	70.80
	Frame	6.77	
	Boxes, surfaces of the wheels and axles	9.40	

Taking : $p = 5.5$ tons. | $\frac{p}{m} = 1.6$ tons.

p', complete load (24 passengers at 154 lbs) 1.66 tons.

$\frac{r}{R}$ 0.075, R = 1.64 feet, we have.

Constant resistance	at the tire	15.80 lbs
	at the journal	46.29
Variable do.		$0.033\ V^2$

If in order to compare the resistances on railways with those on common roads, we take a velocity easily realized equally on the latter, for example, V = 7 miles an hour, we shall have :

(*) *Navier. Notes sur l'architecture hydraulique*, de *Belidor*.

Constant resistance.	61 80
Variable —	10.57
lbs	72.27

or $\frac{72.27}{7.27} = 9.92$ lbs per ton.

At this velocity, the resistance of suspended vehicles is $\frac{1}{30}$ th $= 74\ 66$ lbs per ton on a paved road in a fair state of repair, and it may rise to more than double on indifferent metalling.

At an equal speed, the resistance on an iron road may thus be estimated at the $\frac{1}{7}$ th or $\frac{1}{8}$ th of what it is on an ordinary road; and it must not be lost sight of, on the one hand, that the resistance of the waggons is deduced from a value attributed to f generally very exaggerated, on the other that on railways, the vehicles travel not isolated, but in trains formed of a greater or less number together, which tends to reduce, in the coefficient of traction, the part arising from the resistance of the air; a circumstance which has only a slight importance at the low speed realizable on roads, but considerable at the high speeds, which constitute one of the most valuable qualities of railroads. From the overpowering obligation of uniting thus together in trains, the vehicles which follow the same track, results thus for an element of the resistance often very important (as well as for the cost of driving), a reduction of that element referred to the gross unit transported.

§ IV. — Resistance of a train.

298. The fixed part, or considered as such, of the resistance of a train is simply equal to the sum of the fixed partial distances. It is not so with the variable part; that of the train is, at equal speed, less than the sum of the isolated waggons.

The surface S, which, directly acted against, would undergo a resistance equal to that of the train, comprehends then :

1st, the *front* of the train and the accessory surfaces which, by reason of their distance apart, are attacked in *full* front, that is to say all the pairs of wheels, axle-boxes, etc.; 2nd, a certain fraction of the masked surfaces, that is to say, of all the other bodies but the first.

Dr. *Lardner* endeavoured, by experiments made on the *Manchester* and *Liverpool* line, to determine this last element; he measured the distance run through by the train, to stopping, on a horizontal following an incline, and

that in two circumstances : 1st, with the train not modified, the air acting freely on the bodies; 2nd, after having prevented this action by canvas nailed from one body to another. The distance run through having been no greater in the second case than in the first, Dr. *Lardner* concluded therefrom that the influence of the masked surfaces could be neglected. The same experiment, taken up again later on, showed a very notable influence. This divergence might have been partly in consequence of the inequality of the distances apart; but according to M. *Frimot* (*), one cause of uncertainty affected the first result observed; the velocity acquired from the bottom of the plane by the fall alone beeing too small, it was made up for by an impulse given by an engine at the top of the incline, so that the resistances had afterwards to destroy, not only the work of gravity, but also that somewhat uncertain work which the engine had expended on the train.

From his experiments on the English railways, M. *de Pambour* concluded that, with the rolling-stock on which he experimented, each body masked was equivalent to a free surface of the square feet. The method is not irreproachable; it tends as we shall see (303) to exaggerate the influence of the masked surfaces; but as the transverse dimensions of the bodies, and the spaces between them are greater in the actual stock, M. *de Pambour's* figure is perhaps less inexact at the present time than when he obtained it. In any case, it is admitted for want of a better.

If we consider a train formed of N identical vehicles, for example, of the type considered above (297), each of the N—1 vehicles other than the first introduces a direct surface of $9.04 \times 1 = 10.04$ sq. feet, so that the total resistance of the train is :

$$(a) \qquad \left\{ \begin{array}{l} \mathbf{T} = \mathrm{N} \times 0.001\,(p+p') + \mathrm{N} \times 0.05 \left(p - \frac{p}{m} + p'\right) \frac{r}{R} + \\ \qquad + 0.005\,\mathrm{V}^2\,(5.74 + 0.93\,\mathrm{N}). \end{array} \right.$$

If the wind has any velocity, the horizontal component of which V′ makes an angle α with the direction of the train, to the velocity of the latter must be added, with its sign, $\mathrm{V} \cos \alpha$. The resistance of the medium may then attain enormous values. If for example a train of 10 carriages, weighing 71 tons, was running at 50 miles an hour against a *head* wind animated with the same velocity of its own (a figure which may be reached and even exceeded), V would have the value of 100 miles an hour, and the resistance of the medium would amount to 1.92 tons, or more than 0.026 per ton, seven times greater than the fixed resistances.

(*) Lithographed sheets of l'*École des Ponts et Chaussées*.

Trains have, in effect, been seen, in the plains of *la Crau*, near *Marseilles*, literally stopped by gusts of the *mistral*, and scarcely able to get on their journey again with double auxiliary.

299. *Effect of a side wind.* — As to the transverse component of the velocity proper of the air, it is inoffensive so long as the pressure is not great enough to overcome the friction of the tires on the rails, and press the flanges against the edge of the rails. But carriages and closed waggons offer, sideways, a pretty good hold to the wind, for this effect, although the conicity of the tires tends to prevent it does not suppose a very great velocity of the wind, especially if the load of the vehicles is small.

At the same time, the corresponding increase of the resistance to traction, on a straight line, is much exaggerated; it is slight, and would be the same on a curve if the connections of the axles allowed them to take a radial position thereto. A pressure, even considerable, of the flange against the lateral face of the rail, only involves in that case but a slight resistance, because the distance run through by the friction corresponding to that pressure is only a small fraction of the distance run by the vehicle. The point O (Pl. XV, *fig.* 17) by which the tire rests on the rail, animated with two velocities equal and contrary, is immovable in space; it is the instantaneous centre of rotation of the wheel, and the velocity of any one point of the latter, situate at a distance d from O is $V\frac{d}{r}$, V being the velocity of the vehicle and r the radius of the tire. If the axle is normal to the line, the contact of the flange and the rail takes place on the vertical from O, and the fraction $\frac{d}{r}$ is very small, nearly $\frac{m}{22}$, m being the projection of the flange.

In determining (I, 199) the conditions of the inscription, between the rails of a vehicle with parallel axles, we admitted, in order to fix an obstacle limit, that the curvature of the line, increasing until the rails came in contact with the wheels, that contact would take place on the outside edge of the flange. In reality (II, Pl. XII, *figs* 48 and 49), it is nearly at the middle of the height of the flange m reckoned from the top of the rail that this contact occurs; so that in the actual case, the axle being supposed normal to the line (*fig.* 17), $d =$ nearly $\frac{m}{2}$. The relative space run through by the friction in question, while the vehicle runs through 1, is then $\frac{m}{2r}$, or for $m = 1.18$ inch, and $2 = 1.64$ feet 0:33. But this relative space, and consequently the resistance, increase much if the axle, on account of its attachment, cannot take

a normal position to the line; we shall return to this point when examining the resistance due to curves (313 and following).

If the wheels slide, the position changes immediately, the centre of rotation passes from the point of contact O, to the centre of figure C, and the relative distance run through by the friction of the flange on the rail, becomes :

$$\frac{r+\frac{m}{2}}{r}.$$

In some of the numerous experiments performed on the Lyons railway, by M. *Poirée*, an anemometer formed of a plate of sheet of iron 2.6 square feet above the train, brought the effects on to a special dynamometer, and gave the pressure of the wind.

The resistance per square foot, shown by that instrument, rose as high as 11.25 lbs., this last figure corresponding to a train-velocity of 65.62 feet a second (48 miles an hour), and to a contrary wind. In an experiment made between *Paris* and *Melun*, the speed of the train being 43.12 feet per second (27.34 miles an hour), and the air almost at rest, the anemometer marked a mean pressure of 20 lbs per sq. foot.

At the speed of 35 miles an hour, the total resistance of the same train varied from 14.33 lbs to 23.15 lbs. In the first case, the wind was favourable and inclined at 10° to the direction of the train; in the second, it was contrary and inclined at 28°; the velocity of the wind itself was not given.

A violent wind taking the train crossways, does not confine itself to determining an increase of resistance, then very important. If the reactions of the rail against the flange insure the equilibrium of translation of the vehicle, the strict equilibrium of rotation may be reached and exceeded. We have seen (II, 42) that on the *Narbonne* and *Perpignan* and the *Karst* lines, carriages have been overturned by the wind. A train was also upset, in great part, the 5th of December 1867, near the *Leucate* station (Southern line). From the weight and dimensions of the vehicles overturned, and of those which resisted, it results that the pressure of the wind, almost normal, was over 31 lbs on the square foot (which corresponds to a velocity of 98.5 feet) and below 51 lbs (*). M. *Nordling* concludes from these investigations relative to the stability of metallic bridges, that, even in our climates, a possible pressure of 37 lbs must be reckoned on.

(*) *Annales des Ponts et Chaussées*, 4th series, vol. XXII, 1868, page 219.

CHAPTER II.

MEASURE OF THE RESISTANCES IN A LUMP.

300. τ being the mean resistance per ton of a train of N waggons running over a horizontal of length l, passing from the velocity V to the velocity V′, and T foot-pounds the effective work expended by the motor, we have :

$$\left.\begin{aligned} T-\tau N(p+p')\,l = \frac{N(p+p')}{2g}(V'^2-V^2)+N\left(\frac{V'^2-V^2}{2g}\right)\times \\ \times 0.54\,\frac{p}{m} = V\,\frac{V'^2-V^2}{2g}\left[p\left(1+\frac{0.54}{m}\right)+p'\right] \end{aligned}\right\} \quad (1)$$

an equation which gives τ, if V and V′ are known.

The coefficient τ which has no meaning unless referred to the velocity to which it corresponds, is considered as referring to the mean

$$\text{If } V = V', \quad \tau = \frac{T}{N(p+p')\,l}. \quad \ldots\ldots\ldots\ldots \quad (2)$$

If, which is ordinarily the case, V and V′ are not known, this method is still applicable, provided it be certain that the difference between these velocities is not too great.

It is sufficient then to observe the time t taken to run over the length l, and the mean velocity to which the value (2) of τ corresponds is $\frac{l}{t}$.

The work T may be produced, either by gravity or by an engine. It may also be *nil;* the movement is then retarded :

$$V' \text{ is} < V, \text{ et } \tau = \frac{V^2-V'^2}{2g\,(p+p')\,l}\left[p\left(1+\frac{0.54}{m}\right)+p'\right].$$

§ I. — Measure by gravity

The train being left to itself, without initial velocity, on an incline o

$$\frac{1}{i}, \text{ we have } T = \frac{N(p+p')\,l}{i}.$$

If $V = V'$, (2) gives $\tau = \frac{1}{i}$, which is evident

Example. a : Isolated vehicles. 1st, an empty waggon left to itself on the parabolic incline from *Saint-Germain* to *Le Pecq*, which was the same height as a constant gradient of one in 40, acquired a velocity estimated at 63.34 feet = 42 miles an hour. The resistance on a level of a waggon alone would thus be 0.025 per ton 55 lbs at that speed of 42 miles; a very considerable figure, but which is partly explained : 1st, by the very fact of the waggon being isolated; not being contained as in a train, it took a serpentine movement which brought shocks of the flanges against the rails at intervals; 2nd, by the amount of the resistance of the air which, referred to the unit of weight is much greater for one waggon alone than for one in a train, and for an empty waggon than for a full one. There is besides, some doubt as to the amount of the velocity acquired at the foot of the incline.

301. *Serpentine movement.* — By letting go in the same way, in 1848, a luggage-van down an incline on a straight line, M. *v. Weber* ascertained that the periodical shocks of the flanges against the rails followed each other at distances decreasing as the velocity increased. By means of a trap made in the floor, the flange of one of the front wheels was chalked, and at each shock marked the rail. The interval between these marks, which was from 46 to 56 feet, at the speed of 4.72 miles an hour, went down to 13.5 and 11.2 feet at 33 miles.

The waggon thus described (Pl. XV, *fig.* 18) a succession of arcs, flat enough to be regarded as circular, having the total play j of the line for versed sine, the intervals between the marks d for chords, and for radius ρ the value deduced from :

$$\frac{d^2}{4} = (2\rho - j)\,j, \text{ or } \rho = \frac{d^2}{8j}$$

j was 0.93 inch, whence at 4.72 miles an hour (6.89 feet per second)

$$d = \frac{101.7}{2} = 50.85 \text{ feet}, \quad \rho = 4.856 \text{ feet}.$$

At 33 miles an hour (48.56 feet per second)

$$d = \frac{24.7}{2} = 12.35 \text{ feet}, \quad \rho = 252.6 \text{ feet}.$$

The waggon thus moves, on a straight line, as it would on a series of curves, stiffer and stiffer as the velocity increases, and reversed to each other.

At the same speed, the serpentine movement is the more marked the smaller the wheel-base of the waggon, but this element is not indicated.

It is unnecessary to add that the movements superadded to the translation of the two vehicles in question, had no other origin than a want of symmetry in the dimensions and in the putting together a fault which

should be avoided with the greatest care, and the effects of which are more seriously felt by an isolated waggon than by one forming part of a train with the couplings suitably tightened. An important observation naturally finds its place here.

Equilibrated wheels. — One of the essential conditions of the steady and smooth running of carriages is, especially at high speeds, the exact coincidence of the centre of gravity with the centre of figure. If that does not take place, the forces of inertia not balancing round the axis of rotation, the load on the rail varies at each moment : less than the weight, when the centre of gravity describes its upper semi-circumference, greater, when it describes its lower one ; a minimum, when it is on the vertical and above the centre of rotation, a maximum, when it is on the vertical, and below. Thence a sort of hammering, very perceptible at high speeds, and which soon ends in an unequal wear of the tire and a change in its form.

Wheels with full discs are particularly subject to this imperfection, on account of the irregularity of the thicknesses. It has been ascertained on the Northern of France, that the distance apart of the centres of gravity and of figure is often notable, and explains the observed effects. Thus they apply the known remedy to these wheels, that is to say a counterpoise (II, 278) which neutralizes the influence of the eccentric masses. Its mass and its position are determined by trials, in such a way that the wheel on the lathe may be in equilibrium, in all positions, round its axis. The definitive counterpoise is an iron plate riveted on to the disc, and as near as possible to the rim.

The improvement thus obtained is very appreciable. Thus disc-wheels are never placed at the present time under carriages for high speed, without being previously submitted to a verification, and the defect remedied if there is occasion.

M. *Clauss* has observed that isolated waggons start, with the air at rest, down inclines of one in 625, one in 667, and even one in 714, taking thereon but a very low speed, it is true. The total resistance would thus only exceed by 50 per cent the value (0.001), admitted for the resistance at the tire. The lubrication was no doubt good, it is probable also that the waggons were little loaded, which reduced the fraction of the total weight, developing friction and slipping. The resistance affects, it is true, the unit of weight of an empty vehicle more seriously than that of a full one; but at a very low speed, this influence can be neglected, and disappears against that, contrary and greater, of the diminution of the fraction of the total weight, borne by the journals (307).

302. *b. Trains. Observations made on English railways.* 1st. *Uniform movement.* A train without engine, the composition of which is not indicated, acquired on a incline of one in 100, a uniform velocity of 54.8 feet per second (37 miles an hour). The resistance at this speed would thus be 22 lbs a ton. It was on the narrow gauge. On a similar incline on the broad gauge (7 feet), a train, the composition of which is also not given, is stated to have reached a speed of 75.46 feet per second (52 miles an hour), so that at this high speed on a level, the resistance would only be the same, 22 lbs per ton. Such a superiority of the broad gauge could scarcely be explained, even taking into account the greater diameter of the wheels, and a greater stability of the vehicles on the road.

2nd. *Varied movement.* If the inclined plane is not long enough for a uniform velocity to be acquired thereon, and to continue during the time necessary to ascertain that uniformity, the resistance of the train may be deduced from the distance l' run through a second plane following on to the first, and on which the movement is retarded, and destroyed; l and l' being the respective distances run over on the two planes, $\frac{1}{i}$ and $\frac{1}{i'}$ their rates of inclination, we have

$$\mathrm{P}\left(\frac{1}{i}=\tau\right) l=\mathrm{P}\left(\tau-\frac{1}{i'}\right) l'; \text{ whence } \tau=\frac{li'+l'i}{(l+l')\,ii'},$$

a value which corresponds to the mean velocity $\mathrm{V}=\frac{l+l'}{t}$, t being the time of the total run $l+l'$.

303. The method followed by M. *de Pambour* is founded on the same principle.

Admitting that the resistance of the train of weight P, is of the form $p+qV^2$ (298) and that the second term represents the resistance of the air (q being therefore proportional to the surface directly struck against S_1, equivalent to the *real* surface), we have by applying the principle of work, what is more simple than making use, as M. *de Pambour* did, of *d'Alembert's* principle :

1st. *For accelerated movement on the upper plane*, P′ representing the weight of the train increased by the 0.54th part of the weight of the wheels and axles :

$$\left[\frac{\mathrm{P}}{i}-(p+qv^2)\right] dl=\frac{\mathrm{P}'}{g}\,v\,dv, \text{ whence } l=-\frac{\mathrm{P}'}{2gq}\log\text{hyp.}\left[\frac{\mathrm{P}}{i}-(p+qv^2)+\mathrm{C}\right].$$

At the origin, $v=0$ and $t=0$, whence $\mathrm{C}=\frac{\mathrm{P}'}{2gq}\log\text{hyp.}\left(\frac{\mathrm{P}}{i}-p\right)$. Carrying over

$$l=\frac{\mathrm{P}'}{2gq}\log\text{hyp.}\,\frac{\frac{\mathrm{P}}{i}-p}{\frac{\mathrm{P}}{i}-(p+qv^2}; \text{ and } e \text{ being th base of the hyperbolic system,}$$

$$e^{\frac{2gql}{\mathrm{P}'}}=\frac{\frac{\mathrm{P}}{i}-p}{\frac{\mathrm{P}}{i}-(p+qv_2)}, \tag{1}$$

$$qv^2=\left(\frac{\mathrm{P}}{i}-p\right)\left(1-\frac{1}{e^{\frac{2gql}{\mathrm{P}'}}}\right).$$

When l is large enough for the term $\frac{1}{\frac{2gqL}{P'}}$ to be neglected against 1, qv^2 no longer appreciably increases with l; the movement approximates more and more to uniformity, without ever being able to reach it.

At the foot of the plane, that is to say for $l = L$, we have $v = V$ and

$$qV^2 = \left(\frac{P}{i} - p\right)\left(1 - \frac{1}{e^{\frac{2gqL}{P'}}}\right) \cdots \tag{2}$$

2nd. *For retarded movement on the lower plane.* V being the velocity at the origin, and v' the velocity at the end of distance l',

$$e^{\frac{2gql'}{P'}} = \frac{\frac{P}{i'} - (p + qv'^2)}{\frac{P}{i'} - (p + qV^2)};$$

L being the total distance, for which $v' = 0$,

$$e^{\frac{2gqL'}{P'}} = \frac{\frac{P}{i'} - p}{\frac{P}{i'} - (p + qV^2)}. \tag{3}$$

Equating the value of $q\,V^2$ drawn from this expression, and its value (2), it comes :

$$p = \frac{\frac{P}{i}\left(1 - \frac{1}{e^{\frac{2gqL}{P'}}}\right) - \frac{P}{i'}\left(1 - \frac{1}{e^{\frac{2gqL'}{P'}}}\right)}{\frac{1}{e^{\frac{2gqL'}{P'}}} - \frac{1}{e^{\frac{2gqL}{P'}}}}. \tag{4}$$

For $L = L'$, the denominator would be *nil*. But this equality would involve $\frac{1}{i} = \frac{1}{i'}$, which would reduce also the numerator to 0. As, by hypothesis, $\frac{1}{i}$ is $> \frac{1}{i'}$, L is necessarily $> L'$, and p is positive.

Influence of the surfaces of the bodies masked. Direct equivalent surface. This value of p is a function of $q\,V^2$, that is to say of $0.005\ S_1\ V^2$. Known for a given waggon, the surface S_1 is not so for the train, the masked surfaces undergoing only more or less resistance from the air, supposed at rest.

In order to find this resistance, and consequently S_1, M. *de Pambour* experimented first on each of the waggons of the train successively. He thus obtained, for each vehicle, an expression $m + nv^2$, $m' + n'v^2$, $m'' + n''v\,n$..... in which n, n', n'' were formed as we have seen (297), and m, m', m''... given by equation (4).

That fixed, supposing at first the influence of the masked surfaces of the bodies to be nil, M. *de Pambour* calculated q accordingly for the whole train, that is to say taking simply for S_1 the maximum section of the train, and adding thereto, of course the accessory surfaces directly acted against (wheels, axles, boxes), and he deduced the value of p therefrom, by equation (4).

" It is evident ", he says (*), " that the friction proper of the waggons did not vary; " the *fixed* resultant p of the train must thus have been equal to the sum of the individual fixed resistances of the separate elements : so that $p = m, m' + m''$.....

Now this equality never took place; p was greater than Σm.

Admitting that this excess arose from the error committed, by only bringing, for the whole train, into the coefficient q, the surfaces directly struck against, the direct surface equivalent to the masked surfaces was given by the relation $p - (m + m' + m'') = 0.005\,A\,V^2$; N being the number of waggons, each of the N — 1 bodies introduced thus a surface equivalent to a *direct* surface $\frac{A}{N-1}$. It is thus that M. *de Pambour* found 1 sq. ft., so that every waggon, except the first is equivalent altogether to a direct surface of 1 sq. ft. added to 10 sq. feet (297), or 11 sq. ft.

The exactitude of this mode of valuation is more apparent than real; the part of the resistance, supposed invariable, cannot be so, seeing that the resistances exerted at the tire, increase with the speed. The velocity V at the foot of the first plane, was greater for the train than for the isolated waggons, by the sole fact that, for the first, the resistance of the air acted on a much smaller surface relatively to the air. This greater velocity reacted on a portion of the resistances comprised in the term p, and the excess $p - \Sigma m$ was only, on that account, partly imputable to the resistance of the air on the masked surfaces.

M. *de Pambour's* result was thus more or less exaggerated; no scruple is made in still applying it as it is, which is however admissible, the primitive exaggeration of the figure being compensated, and perhaps more than that, by the greater wheel-base of the actual waggons.

Those who express surprise that the practice of railways should so often be reduced to experiments thirty or thirty-five years old, would not be altogether wrong. But in the actual case, it is a little also the fault of the nature of the question. It is a work not possessing much attraction, the determination of resistances so variable, so capricious; the results are only applicable in the conditions under which they have been obtained; and their application would suppose, by that fact, previous investigations, such as on the velocity and intensity of the wind.

Admitting the above figure, the resistance opposed by the air at rest, to a rain of N waggons of the dimensions indicated (297), is represented by the erm :

$$0.0001\,V^2\,[0.8 + 11\,(N - 1)] = 0.0001\,V^2\,(59.8 + 11\,N).$$

Experimenting on the *Stockton* and *Darlington* line, as did Mr. *Wood* and M. *de Pambour* on inclines followed by a horizontal, in very calm weather, and at a speed low enough for the resistance of the air to be neglected,

(*) *Traité des locomotives*, page 144,

Mr. *Dixon* found 11.9 lbs on the average for isolated waggons : a considerable figure, which, according to him, is decomposed as follows :

Resistance at the journals : 75 per cent; at the tires 25 per cent.

He scarcely found in the same stock, any two waggons having the same resistance.

§ II. — Measure by the dynamometer.

304. The means most adopted, because it can be applied to all conditions of section, and to the trains in current service, consists in interposing a totalling dynamometer between the tender and the train. Marking off the telegraph-posts (the telegraph-posts are often distributed in a very irregular manner) allows of determining with the greatest ease the velocity corresponding to the portions of the diagram for which the effort of traction oscillates round a constant value, and the correction due to the value of the section is made, if there be occasion, immediately.

Ordinarily, however, it is considered enough to refer the mean resistance, deduced from the diagram, to the mean velocity deduced from the length of time taken by the journey, deduction being made of the times of stopping.

The following, for example, is the result of an old experiment made on the *Lyons* line: ordinary train from *Paris* to *Melun* and back :

Weight of the train drawn N $(p + p')$.		46.00	
Total distance run (there and back)	$t =$	281.504	feet
Motive power given by the area of the diagram T = ...		285 327.384	ft lbs.

whence $\left\{ \frac{286.327.384}{46 \times 2240 \times 281.504} = 22 \text{ lbs per ton.} \right.$

The total length of time of the journey (stoppages deducted) being 7.072, the mean velocity to which this resistance corresponds is $\frac{281,504}{7,072} = 39.93$ feet per second, or 47.06 miles an hour.

The figure of 22 lbs per ton does not include the whole effort of traction, the dynamometer not recording the portion of the resistance of the air which is applied directly to the motor.

If we desire to compare with the figures thus obtained, those given by the formula $(a, 299)$, its last term must be modified so as to take into account that part of the front of the train masked by the tender, which reduces the number 59.8 to 21.50 nearly.

Thus modified, this formula gives for the preceding example, 12.13 instead of 22 lbs, that is to say much less than observation gives, and that notwithstanding the exaggerated value attributed to f (293,305).

This apparent disagreement is explained.

The effort given by experiment includes many other elements than that given by the formula.

First, and although the difference of level between the two extreme points is slight, it is not in general sufficient to take the mean of two journeys in order to eliminate the influence of the gradients. The line passes over, in this actual case, a secondary ridge; on each side, the increase of effort on the ascent, is not compensated by its diminution on the descent, if a part of the excess of work developed for the one, must be partly destroyed by the brakes during the other. At the same time, in the present case, this cause may almost be neglected, the inclines of one in 200, or one in 167 on both approaches, requiring but slight assistance from the brakes.

2nd, at each stopping-station (it is an ordinary train we are dealing with) the brakes destroy, or rather convert into heat, the *vis viva* of the train; the motor must afterwards restore it, and this restitution is comprised in the total T ft. lbs.

3rd. Although the curves of this section are of large radius, they increase however to a certain extent, the resistance on a straight line to which the formula applies.

It is, certainly, very useful to know the mean resistance of a train drawn over a given line, and under determined conditions of service; but care must be taken not to confound the complex result with the simple one, corresponding to uniform movement on a horizontal and straight line.

305. *Experiments made on the Lyons railway.* The engineers of the Lyons railway made, in 1860, several series of very careful experiments on the resistance of trains at low speeds; they had mainly for object the comparison of two methods of lubrication, by grease and oil. In this respect, they have led to a result already quoted (II, 75) which may seem paradoxical, but which is explainable; there is nothing more variable than the nature and the lubricating value of greases and oils. A grease of very good quality, composed so as make allowance for the season, may be as good as an ordinary oil, and better than an indifferent oil. But it is not in the relative values that the interest in the figures obtained mainly exists, it is in their absolute values.

First series.

Twenty new coal-waggons (S f) were fitted up : ten on boxes with grease, and ten with oil-boxes (lubrication below by means of a roller pressed up by a spring) :

Gross weight of each waggon.		10 tons
Journals. .	Length	6.30 inches
	Diameter	2.95 —
Diameter of wheels at the tire.		3.02 feet.
Weight of one pair of wheels $\left(\frac{1}{2}\frac{p}{m}\right)$		0.73 tons.

After having had the *edge taken off* by a run of 250 miles, without a single stoppage for hot boxes, the waggons were made into two trains : one with the ten oil waggons, the other with the ten greased waggons, each of them completed by a six-wheeled 3rd class carriage, weighing 7 tons, which carried their weight to 107 tons. Each of them made two journeys the same day, going and returning, between *Paris* and *Brunoy*. In order to equalize the mean temperature, the oil waggons and those with grease took the first and last train of each day in turn.

The effort was measured by a *Morin* dynamometer, having a deflection of 1.57 inches per ton, installed at the hinder part of a special van placed between the engine and the experimental train. The distance, run as regularly as possible, was marked at each kilometre (0.62 mile) on a roller which received also a mark every 10 seconds.

The mean of the ordinates of traction, taken off every 100 metres (328 feet) gave the draught.

In order to establish these means, only kilometres run over with uniform velocity were taken into account. The efforts at starting varied much, according to the velocity started with.

The following table gives an abstract of the results of this first series (eight days of experiment).

ABSTRACT (1st SERIES).

DATES of the experiments.	VELOCITY in feet per second.		VELOCITY in miles per hour.		MEAN TRACTION IN LBS PER TON				OBSERVATIONS.
					ON A HORIZONTAL.		ON ONE IN 250.		
	Grease.	Oil.	Grease.	Oil.	Grease.	Oil.	Grease.	Oil.	
7th of April 1860	28.15	30 65	19.2	20.9	Going 6.39 / Coming 6.56 } 6.61	Going 6.06 / Coming 5.29 } 5.66			(*) Gravity deducted.
	28.64	29.01	19.3	19.7					
10th do.	29.13	28.38	19.8	19.3	Going 5.97 / Coming 7.72 } 6.83	Going 6.24 / Coming 8.22 } 7.23			
	28.94	27.07	19.7	18.4					
23th do.	32.81	28.78	22.4	19.6	Going 10.67 / Coming 7.91 } 28	Going 10.52 / Coming 6.50 } 8.57			Wind S. W. strong and varying force no wind.
	30.68	28.68	20.8	19.3					
24th do.	28.84	27.69	19.6	18.8	Going 4.89 / Coming 4.89 } 4.89	Going 5.97 / Coming 5.60 } 5.78			
	28.12	24.38	19.2	16.6					
	20.93	18 83	14.3	12.9	. . . . .	. . . . .	12.06	14.18	
							3.24 (*)	5.36 (*)	
25th do.	32.02	29.47	21.8	20.0	Going 5.11 / Coming 5.09 } 5.09	Going 7.10 / Coming 5.18 } 6.13			Rain, no wind.
	29.53	24.87	20.0	17.0					
	18.17	19.70	12.4	13.4	. . . . .	. . . . .	12.30	13.34	
							3.48 (*)	4.52 (*)	
26th do.	35.80	32.42	24.4	22.0	Going 5.75 / Coming 7.54 } 6.61	Going 6.94 / Coming 9.83 } 8.38			Wind N. E.
	29.33	29.54	19.9	20.2					
27th do.	32.35	35.60	22.0	24.2	Going 6.17 / Coming 6.48 } 6.32	Going 6.33 / Coming 6.65 } 6.48			Wind N.
	28.33	31.53	19.3	21.5					
	20.54	20.15	14.0	13.7	. . . . .	. . . . .	12.68	13.54	
							3.86 (*)	4.72 (*)	
28th do.	33.73	29.88	23.0	20.4	Going 6.06 / Coming 5.29 } 5.67	Going 7.76 / Coming 5.97 } 6.92			Wind N.
	35.50	29.98	24.2	14.20					
	21.13	21.43	14.2	14.6	. . . . .	. . . . .	12.74	13.23	
							3.75 (*)	8.81 (*)	

An inspection of this table shews :

1st. As we said, the sustained superiority, save in one case (23rd of April) of grease over oil.

The preparation of the grease on that line, had always been the object of particular attention; we have seen besides (II, additions, p. 819) that a more continued investigation of the question, taken as a whole, determined the company to adopt oil exclusively; a fact which the good quality of the grease renders all the more significative.

2nd. The considerable inferiority of the resistance proper (total resistance with gravity deducted) on a gradient of one in 250, relatively to the resistance on a horizontal.

We conceive that going up an incline, the couplings being more strained, impart a steadier motion to the vehicles, and diminish the resistances due to the serpentine movement, to the shocks of the flanges against the rails.

M. *Polonceau* thought he had noticed that a gradient of α inclination, does not increase the coefficient of traction quite by $\sin \alpha$. Rigorously, that is evident; the coefficient of traction, r on a level, becomes on the gradient, $\sin \alpha \times r \cos \alpha$: the increase is thus $\sin \alpha - r\,(1 - \cos \alpha)$, or putting :

$$\alpha = \frac{1}{i}, \frac{1}{i} - r\left(1 - \frac{1}{i}\sqrt{i^2 - 1}\right).$$

Now, even on the steepest gradients on railways, unity is absolutely to be neglected against i^2; so that if as M. *Polonceau* thought, the increase of effort, corresponding to an increase of inclination equal to 0.001, were only 0.0009, that fact should be attributed to the cause pointed out just now. If, moreover, that cause is real, its influence is in general very slight; for all the experiments taken together, establish incontestably that gravity enters certainly into the effort of traction to the extent due to the inclination of the gradient.

So it could hardly be explained that that influence would go, as in the experiments of the *Lyons* company, so far as to reduce to 3.24 lbs a resistance which, on a horizontal, rises to at least 4.89 lbs (with grease, no wind). But there is no going into these observations, far too few, on traction up inclines, especially in the face of the somewhat vague indications as to the intensity and direction of the wind, which might have modified the results.

Value of the coefficient of friction of the journals. — It is interesting to see to what consequences these results lead, so far as regards the coefficient f.

Let us take the value 4.89 lbs given by the experiment of the 24th of April

(grease) in which the wind was *nil*. The identity of the values, both going and coming, is besides a further guarantee of their exactness. The formula (α, 298) gives :

$$0.00222 = f \times \frac{0.075}{0.92}\frac{(107.000 - 23 \times 730)}{107.000} + f_1 + \frac{0{,}005SV^2}{107.000}.$$

Admitting $f_1 = 0{,}001$ (291), and neglecting the term of the resistance of the air, which ends by exaggerating f, it gives $f = 0{,}018$, a value which was certainly not reached during the experiment in question, all the more as at the already notable velocity of the train (19.5 miles an hour), the resistance of the air could no longer be neglected.

There is thus a fresh confirmation, very clear, of the exaggeration of the value 0.05 attributed to f.

306. *Second series of experiments.* — This time the ten waggons, with grease, of the preceding series were taken, and ten of the Orleans system on oil-boxes, the latter having the same journals as the first, but wheels of 3.28 feet diameter instead of 3.02 feet, and weighing 0.83 ton instead of 0.73. The trial train, run equally between *Paris* and *Brunoy*, included the twenty waggons, and two dynamometer-waggons (the one in front gave the total traction; the other placed between the two groups, gave the traction of the second), plus a brake-waggon behind all. There was only one journey made each day, going and coming, and the relative position of the group with grease and the group with oil, was changed every other day (Pl. XV, *fig.* 19).

In the Orleans boxes, the oil was distributed, not as in the Lyons oil-boxes, by a roller only touching the journal on a very small surface, but by a cushion pressed up by springs and taking hold of the journal on its whole length and on a considerable breadth.

Each of the twenty trial waggons was loaded so as to weigh ten tons gross, the dynamometer waggon in the middle, weighed 5 tons, and the brake-van 4.57 tons.

Total weight of train drawn by the first dynamometer, with a flexure of 0.72 inch per ton.	209.59 tons say 210 tons.
Weight of the portion drawn by the second dynamometer, with flexure of 1.58 inches per ton. . . .	104.57 — say 105 —

The following table gives an abstract result of the five days experiments :

ABSTRACT (2nd SERIES).

DATES of the experiments.	VELOCITY in feet per second.	VELOCITY in miles per hour.	MEAN TRACTION IN LBS PER TON ON A HORIZONTAL. Grease.	MEAN TRACTION IN LBS PER TON ON A HORIZONTAL. Oil.	MEAN TRACTION IN LBS PER TON ON ONE IN 250. Grease.	MEAN TRACTION IN LBS PER TON ON ONE IN 250. Oil.	OBSERVATIONS.
11th of June 1860	28.88	19.6	Going 6.90 } 5.89	Going 9.57 } 7.36			(*) Gravity deducted.
	25.92	17.7	Coming 4.87 }	Coming 5.16 }			
	24.44	17.0	. . . . .	. . . . .	12.59	15.23	
					3.74 (*)	6.48 (*)	Wind S.
12th do.	28.28	19.2	Going 8.05 } 6.11	Going 8.86 } 7.10			
	27.86	18.9	Coming 4.19 }	Coming 5.36 }			
	23.86	16.3	. . . . .	. . . . .	13.23	13.69	
					4.41 (*)	4.87 (*)	Wind S.
13th do.	28.19	19.2	Going 5.62 } 4.83	Going 7.31 } 6.24			
	28.91	19.7	Coming 4.03 }	Coming 5.09 }			
	23.85	16.3	. . . . .	. . . . .	12.79	12.79	
					3.97 (*)	5.80 (*)	Wind S. slight.
15th do.	24.15	16.5	Going 5.20 } 4.63	Going 6.04 } 5.64			
	25.89	17.6	Coming 4.08 }	Coming 5.27 }			
	22.26	15.1	. . . . .	. . . . .	13.45	13.36	
					4.63 (*)	4.54 (*)	Wind S.
16th do	26.94	18.3	Going 8.51 } 6.39	Going 5.64 } 4.92			
	25.30	17.1	Coming 4.70 }	Coming 4.19 }			
	25.23	16.5	. . . . .	. . . . .	14.37	16.40	
					3.56 (*)	5.38 (*)	

These results agree well with the preceding ones.

The oil-waggons again give resistances constantly superior to those of the grease-waggons : which seems all the more against the use of oil, as in this case the waggons are no longer identical.

The *Orleans* waggons, of the same weight, had the advantage at the same time, of a little less load on their journals, of a smaller distance run through by their friction, and of less resistance at the tire, consequences of the greater diameter of the wheels. These advantages must therefore have been more than compensated, by the inferiority of the *Orleans* oil, relatively to the Lyons grease.

Moreover, the advantge of oil is not absolute. It depends on the differences of temperature. Above 60° (F), grease is as good as oil. If the second is generally preferred at the present time, that is on account of its not being affected, like grease, by low temperatnres, and its composition not requiring to be modified according to the season.

307. *Third series of experiments. Influence of the useful load on traction per ton.* This series had especially for object to appreciate, always acting comparatively on grease and oil, the influence of an increase in the load of the waggons, the gross weight of which was carried to 14 tons.

Going back to the general expression $\frac{T}{N(p+p')}$ (298), of the resistance per unit of weight, of a train composed of N identical waggons :

$$t = f\frac{r}{R}\left(1-\frac{p}{m(p+p')}\right)+f_1+\frac{0.005\,\Sigma V^2}{N(p+p')},$$

we see : 1st, that the load p' increasing, the first term increases, while the third diminishes. Which is besides evident, for the one, because the weight added altogether on the two resistances of the wheels, tire and journal; for the second, because the total resistance of the air is spread over a greater weight.

We conceive besides, that, beyond a certain limit, the coefficient f would increase with the load per unit of surface of the journal.

The experiment was made like the preceding one, but reducing to five the number of waggons of each fraction of the train, with grease and with oil.

Weight drawn by the front dynamometer	10 waggons 14 tons each.	140.0 tons	149.6 say 150 tons.
	Dynam. wag. intermediate	5.0 —	
	Brake-van behind	4.6 —	
Weight drawn by the intermediate dynamometer . .	5 waggons 14 tons. . . .	70.0 tons.	75 tons
	Brake-van	5.0 —	

The spring-grease of the preceding experiments, in the Lyons waggons, had been replaced by summer-grease.

ABSTRACT (3rd SERIES).

DATES of the experiments.	VELOCITY in feet per second.	VELOCITY in miles per hour.	MEAN TRACTION IN LBS PER TON ON A HORIZONTAL. Grease.	MEAN TRACTION IN LBS PER TON ON A HORIZONTAL. Oil.	MEAN TRACTION IN LBS PER TON ON ONE IN 250. Grease.	MEAN TRACTION IN LBS PER TON ON ONE IN 250. Oil.	OBSERVATIONS.
20th of June 1860	26.71	18.2	Going 5.64 } 5.09	Going 5.64 } 4.92			(*) Gravity deducted.
	28.84	19.6	Coming 4.56 }	Coming 4.19 }			
	22.02	15.0	. . . . .	. . . . .	13.82	14.46	
					5.00 (*)	5.64 (*)	
21st of June	29.47	20.1	Going 5.93 } 6.06	Going 7.23 } 6.79			
	29.78	18.3	Coming 6.22 }	Coming 6.85 }			
	22.71	15.4	. . . . .	. . . . .	13.34	12.81	
					4.52 (*)	3.99 (*)	

The increase of the load up to the limit indicated (14 tons), does not then appreciably modify the draught.

Oil would seem, according to these figures, and contrarily to expectation, to regain, if not its advantage over grease, at least to equal it, when the load increases.

It is generally admitted as an established fact, that, all else being equal, number of waggons and speed particularly, the resistance per ton of the train is so much the less, the more it is loaded : but we see that two contrary effects are present : the increase of the effort due to the friction at the journals, and the diminution of the effort due to the resistance of the air. According to the preceding experiments, at speeds bordering on 19 miles, the two causes compensate each other; for greater speeds the second would carry the day, and the traction per ton would be less.

In order to explain the generality often attributed to the reducing influence of the load, and its pretended independence of the speed, the tendency of the waggons to take a serpentine course on the line is alleged, a tendency to which, it is added, they yield the more easily, the less loaded they are. To which may be replied, that, the lighter the waggon, the slighter is the effort required to maintain it in the mean position on the rails. The tendency in question increases besides with the speed.

308. *Influence of the length of the train, of equal weight.* One word, on this subject, as to a question involved, that of the influence, weight being equal, of the number of waggons, or, in other terms, of the length of the train, abstraction of course made of curves, respecting which there has been no question hitherto, and to which we shall soon come (313). Let us put $N(p+p')=P$, the expression of t (307) becomes :

$$t=\frac{fr}{R}\left(1-\frac{Np}{mP}\right)+f_1+\frac{0.005\,\Sigma V^2}{P}.$$

For the same value of P, the first term diminishes when N increases; the third increases on the contrary, seeing that Σ increases. As long as V is not very small, the influence of that term is predominant, so that t increases. This is what experience proves, in effect; the cause indicated does not itself appear sufficient always to explain the real increase of t; it is remarked in general that the serpentine movement of the vehicles increases from the head to the tail of the train. This movement, due to imperfections, which the attention paid to the construction of rolling-stock is gradually

reducing, thus attains an amplitude, and consequently a corresponding resistance, a more or less great mean intensity, the longer the train.

Experiments made on the Eastern of France.

1st, *Goods* (grease).

Speeds . . { 10.5 to 16.2 miles an hour . . . . . 6.94 lbs.
{ 16.2 to 19.9 — . . . . . 8.71 —

Much higher figures than those of the *Lyons* line, partly, no doubt, owing to the grease being of worse quality.

2nd, *Passengers*.

— *a. Short trains* (eight to ten carriages).

Speeds. . . { 28.59 miles an hour . . . . . 15.90 lbs
{ 35.10 — . . . . . 21.10 —
{ 47.20 — . . . . . 31.48 —

— *b. Long trains* (fourteen to seventeen carriages).

Speeds. . . { 28.00 miles an hour . . . . . 13.18 lbs
{ 31.30 — . . . . . 14.40 —
{ 37.30 — . . . . . 17.75 —

The reducing action of the greater number of waggons, *all equally loaded*, or in other terms, of the diminution of the resistance of the air referred to the ton gross, is thus very marked in this case, notwithstanding the contrary influence of the number of waggons of *equal total weight* of the train.

M. *Forquenot's experiments on Orleans line.*

SPEED.	RESISTANCE.	NUMBER OF WAGGONS.
miles an hour.	lbs.	
15.50	4.96	30 to 42
18.60	5.51	30 to 42
24.90	6.61	16 to 18
37 30	8.82	10 to 12

The two last figures are very low, and lead to a slighter influence being attributable to velocity than is usually supposed.

M. *Poirée's* experiments had led him to admit the following figures :

Ballast, 7.05. | Goods, 9.92. | Ordinary, 16.98. | Direct, 18.74. | Express, 22.05 lbs.

309. *Experiments made in England by Mr. Gooch (dynamometer), broad gauge.*

Speeds in miles per hour.	Resistance per ton of the train drawn. lbs.
Train of 100 *tons.*	
13.1	7.56
20.0	8.53
45.0	16.01
57.0	21.91
57.4	23.75
60.0	22.20
Train of 80 *tons.*	
52.6	20.77
Train of 50 *tons.*	
22.1	9.50
44.4	14.66
58.0	22.51

The weight of the train varied by the number of vehicles, and not by their load with an equal number.

The draught increased for the unit of weight, at a perceptibly equal speed, when the weight of the train diminished, the direct action of the air on the front surface of the train being spread over a less number of waggons and of tons.

310. *Experiments made in Germany.*

1st. Experiments made by M. *Kirchweger :* train of coal-waggons, loaded; gross weight drawn : 63 tons.

1st. Very low speed 9.8 to 7.12 miles an hour
Mean resistance on one in 300, 11 lbs, or 3.7 lbs, gravity deducted.
2nd. Speed from 22.4 to 24.9 miles an hour, 4.63 lbs.

The difference 4.63 — 3.75 = 0.88 lbs represents the influence of the increase of velocity. " The figures 3.75 and 4.63 lbs are ", says the author, " the values obtained by deducting from the effort of traction on the piston : 1st, the resistance of the machinery; 2nd, the resistance of the engine as a vehicle; 3rd, the resistance of the air acting directly on the engine ". But the exactness of the figures so obtained, can be the less relied on, as the mean effort on the pistons was not given by an indicator, but by the constantly uncertain calculation of the function $\frac{pd^2l}{D}$.

2nd. *Experiments made in* 1869 *on the* Cologne *and* Minden *line.*

Train formed of forty coal-waggons and a waggon carrying the dynamometer (a simple *Schaffer* index dynamometer).

	EMPTY TRAIN. — WEIGHT 233 TONS.		LOADED TRAIN. — WEIGHT 636.6 TONS.	
Speed.....	16 miles an hour.	25 miles	14 miles an hour	25 miles.
Resistance.....	6.17 lbs	8.42 lbs	3.31 lbs	4.85 lbs

These figures (pretty well in accord with those of the *Lyons* experiments on loaded trains) confirm the influence of the useful load on the draught per ton, with an equal number of waggons (307); it would already even be very appreciable for the low speed of about 14 or 15 miles an hour.

3rd. *Experiments made on the* South Austrian. Isolated waggons.

SPEEDS.	RESISTANCE PER TON.	
	American waggons with eight wheels.	Covered waggons with four wheels.
miles an hour.	lbs	lbs
9.4	4.96	5.14
9.3 to 14.1	5.31	»
14.1 to 18.6	5.91	»
18.6 to 23.6	6.44	6.02
23.6 to 28.3	6.94	6.39
28.3 to 32.9	»	7.08

From these figures would result, on the one hand, the equality of the two types of waggon, which is only natural on a straight line, and on the other, the rather slow progression of the resistance with the velocity.

§ III. — **Empirical formulæ.**

311. As is always the case, when the establishment of a simple and at the same time rational formula is impossible, it has been sought to construct, according to the results of the divers experiments, empirical formulæ reproducing these results more or less exactly, only containing explicitly, as variables, the most important elements, and applicable only to the circumstances in which the variables are comprised, or nearly within the limits of the experiments.

Let us go rapidly over these formulæ, insufficient although useful after

all, provided they be not applied under conditions differing from those yielding them, and especially to stock of quite another design.

1st. One of the oldest, which was used in France at the outset of railways, is very brief; it contains no other variable but the speed; it is the following (r = resistance in lbs per ton)

$$r = 0.00926 + 0.00008106\ V^2 \text{ (V being miles per hour)}$$

It is founded on the hypothesis that the resistance of a train of weight P, is of the form $P(\alpha \times \beta V^2)$; and the two coefficients were determined by the observation of the uniform velocities (16.4 and 43.96 feet per second) acquired by trains left to themselves on two inclines, one of one in 200, on the *Versailles* line (right bank) and the other of one in 100, on the Versailles line (left bank).

It evidently gives, at low speeds, exaggerated values for carrying stock, seeing that they exceed 9 lbs a ton; this is because it does not express the resistance of the waggons alone.

The train had its engine in front, the regulator closed. The resistance, balanced by gravity, was thus composed : 1st, of that of the train including the engine as a vehicle; 2nd, of the minimum resistance of the machinery; 3rd, of the resistance due to the compression of the air by the pistons (148,3rd); a very small amount however, if the slide is at its full travel, and if the blow-off cocks are open.

The resistance given by the formula is thus greater than that of the train drawn, and smaller than that of the gross train, measured on the pistons.

2nd. The results of M. *Gooch's* experiments on the broad gauge (7 feet) are represented, up to a certain point by an analogous formula of Mr. *D. K. Clarke* :

$$r = 8 + \frac{V^2}{171},$$

3rd. Use is still often made, for passenger-trains, and even for the others (II, 394) of a less brief formula established by Mr. *J. Scott Russell*, according to experiments made on inclines, about 1846 by Mr. *Windham Harding* (narrow gauge) and bears the name of the latter :

$$t = 6 + 0.15\ V + 0.00253\ \frac{S\ V^2}{P},$$

It gives, in lbs per ton, the resistance of the gross train, weighting P tons, this resistance being measured to the circumference of the motor wheels, and accordingly the resistance of organs being left aside; V is the velocity in miles-hour and S the maximum transversal section of the train.

As shown by the table below, taken from Mr. *D. K. Clarke* (*), it reproduces, with but indifferent exactness, observed results. Excepting on two experiments out of thirteen, it is in excess, so that the want of agreement cannot be attributed to the velocity of the wind itself, which at the same time is not always unfavourable, although it increases, oftener than it diminishes the resistance. Altogether, the difference, considerable at low speeds, is admissible at high.

NUMBER of vehicles.	VELOCITY.		WEIGHT of the train in tons.	RESISTANCE PER TON, LBS		WIND.
	miles an hour.	feet per second.		observed.	calculated.	
2	14.00	20.7	9	12.39	13.67	Favourable.
4	16.00	23.0	21	8.36	12.99	do.
8	20.00	29.5	43	8.36	13.87	do.
4	21.00	30.8	18	12.39	16.42	do.
8	26.00	38 4	41	12.39	16.82	do.
8	27.00	39.4	41	12.39	17.39	do.
4	32.00	47.2	14	22.10	26.53	Calm.
6	36.00	52.5	30	24.58	22.71	Pretty calm.
4	37.25	54.5	20	24.58	27.94	Favourable.
3	47.00	68.9	32	33.07	32.55	Slight.
6	50.00	73.5	30	32.35	34.64	Calm.
5	54 75	80.7	26	35.36	42.77	Slight.
4	60.00	89.6	22	51.72	53.88	Calm.

312. Although limited, the range of the velocities is still too great for one single empirical formula to be able to represent with tolerable accuracy, and only for the case of the air at rest (or of a wind having a known velocity, and the same direction as the train), the resistances corresponding to them. It is thus desirable to divide the whole series of experiments into groups with slight differences in velocity, and to establish a particular formula for each of these.

This is what has been done by Mr. *Vuillemin* and his collaborators; the following are their formulæ (**) :

A. *Goods.*

V from 7.5 to 20 miles an hour; temperature 59° (F.). The term in V^2 may be neglected :

(oil) . . . . . $r = 3.64 + 0.175\,V.$

(grease) . . . . . $r = 5.06 + 0.175\,V.$

B. *Mixed* and *passenger.*

1st V from 20 to 30 miles an hour . . . . . $r = 3.97 + 0.28\,V + 0.0047\,S\,V^2,$

2nd V fron 30 to 45 miles an hour . . . . . $r = 3.97 + 0.28\,V + 0.0038\,S\,V^2,$

3rd V from 45 to 50 miles an hour . . . . . $r + 3.97 + 0.49\,V + 0.0025\,S\,V^2.$

(*) *Railway machinery*, p. 29.

(**) *De la résistance des trains*, etc., pages 55 and 56.

The two first expressions, independent both of the weight of the train and of the very variable load, in the case of goods-waggons, evidently could not suit both the extreme states : loaded train, and empty train. It is no doubt the first they suppose.

M. *Fink*(*) distinguishes two situations : one including the favourable circumstances, the other the unfavourable circumstances.

1st. Favourable conditions : No curves, or few of a less radius than 550 yards; wind slight; temperature, above 40° (F.); oil-lubrication; load, more than 100 tons gross :

$$r = 5.5 + 0.00571\ V^2.$$

2nd. *Unfavourable conditions* (but not however extreme): Numerous curves of less than 550 yards; wind strong; temperature, below 40° (F.); grease; load below 100 tons :

$$r = 8.25 + 0.00856\ V^2.$$

These two formula, applicable to ordinarily constructed rolling-stock, that of the Austrian Staats-Bahn company, give the following values, which may be usefully consulted.

Velocities, miles an hour...		7.5	9.3	12.4	15.5	18.6	21.7	24.9	31.0	37.2	43.5
Resistances....	1st. form.	lbs 5.63	6.02	6.39	6.90	7.50	8.20	9.04	11.02	15.45	16.31
	2nd. do .	» 8.82	9.02	9.59	10.36	11.24	12.30	13.56	16.54	20.17	24.47

(*) *Zeitschrift des Oesterreichischen Ingenieurvereins*, 1870.

CHAPTER III.

SPECIAL RESISTANCES DUE TO CURVES.

313. In what precedes, we have made abstraction of the curves. The numerical results and the empirical formulæ cited in the preceding chapter, only apply then to straight lines, or at least to curves of very large radius.

Curves add an element of resistance which it is, in practice, very difficult to estimate *a priori*, because it is intimately connected, and according to rather complicated laws, with the peculiarities of the construction of the rolling-stock. There is only one case in which this determination is possible: that in which the stock is constructed in the absolute conditions of rigidity we assumed at first (II, 3). This gives a higher limit of the additional resistance.

The lower limit may be *nil*. It would be very nearly so for a stock constructed in such a manner that the axles, by their mutual connections should always take a position normal to the line, and with independent wheels, getting rid of the sliding at the tires. M. *Arnoux's* articulated stock fulfils these conditions partly; with the exception of the locomotive and the front and end carriage, which are provided with guiding-rollers, the resistance is perceptibly the same on a curve, and on a straight line.

The resistance due to a curve of given radius approaches more or less one or the other limit, according as the contrivances described higher up (II, 176 and following, 329, 334 and following) have been more or less widely applied. Between these two extremes: forced movement of the rigid stock, free movement (or nearly so) of the articulated stock, all the intermediate states are possible, and it is from experiment that an estimate of the total resistance must be expected; an estimate already so incomplete, even in the particular case in which the radius is infinite (289 and following).

§ I. — Increase of the resistance on a curve of the rigid stock.

314. Let us then suppose the axles invariably parallel, and let us neglect even the slight conicity given to the tires independently of all consideration of curves, and, as we have seen (II, 4), in order to improve the conditions of running on a straight line; let us make abstraction also of the lifting of the outer rail (I, 199, and Pl. VIII, *figs.* 7 and 8; II, 176 and 179).

The increase of resistance on a curve of radius ρ is due :

1st, to the sliding at the tire; 2nd, to the parallelism of the axles; 3rd, to centrifugal force.

1st. *Sliding at the tire.* One of the wheels, the inside one for example, running through the unit of length, the other runs through $1 \times \frac{\rho + e}{\rho}$; the sliding is thus $\frac{e}{\rho}$; P being the weight of the pair of wheels and of its load, the friction is $\frac{f\mathrm{P}}{2}$; the work, $\frac{f\mathrm{P}e}{2\rho}$, and the effort per unit of weight $\frac{fe}{2\rho}$.

For $\mathrm{F} = 0.2$, $\rho = 820$ feet, this is 1.32 lbs per ton.

2nd. *Parallelism of the axles* (Pl. XV, *fig.* 20). The rectangle $a\ b\ c\ d$ of the points of support of the wheels on the rails, the slight distance apart of which points relatively to the perpendicular of the respective centres of the wheels we may neglect (290), pivots at each instant round the vertical of the centre of figure of the vehicle, under the action of the contrary pressures applied, by the outside rail, on the flange of the front-wheel, and by the inside rail, on the flange of the hind-wheel; the effect of this couple is to produce at each instant a transverse sliding of the tires on the rails.

Let us consider the point of contact a carried on to a', at a distance $a\ a'$ small enough for its curvature to be neglected. On a straight line, a would have come on to a''. Thus, when a, that is to say the vehicle, runs through $a\ a'$ along the curve, the amplitude of the transverse sliding is $a'\ a''$; thus when the waggon runs through the unit of length, the distance run through by the transverse sliding is $\frac{a'\ a''}{a\ a'}$; now, admitting that the

transverse axis M N, of the waggon, is directed along the radius of the curve, on account of the similar triangles $a\,a'\,a''$, $c\,a\,\mathrm{M}$,

$$\frac{a'\,a''}{a\,a'} = \frac{d}{2\,\rho}.$$

P being the weight of the vehicle, the wheel a carries $\frac{\mathrm{P}}{4}$; the increase of work is thus $\frac{f\,\mathrm{P}\,d}{8\,\rho}$, and $\frac{f\,\mathrm{P}\,d}{2\,\rho}$ for the four wheels; and the increase of traction per unit of weight is $\frac{f\,d}{2\,\rho}$.

For $\rho = 820$ feet, $d = 11.8$ feet, $f = 0.2$; this comes to 3.09 lbs.

3rd. *Centrifugal force.* If it were a question of a pair of wheels alone, the increase of the effort of traction, due to the centrifugal force, would be very slight, because the relative distance run through by the corresponding friction would be very small. We have already pointed out (299) that the absolute movement of the wheel is at each instant a rotation round the point of contact O of the tire with the rail, in such a way that the distances run through by the wheel, that is to say by the vehicle, and of the friction in question, are in the same ratio as the radius and the distance from the point O to the point of contact of the edge of the rail and the flange.

If the axle can take the radial position (*fig.* 17), the pressures of the flange and of the rail are mutually distributed, making abstraction of the curvature of the flange and the rail, on the circular segment ABC, and the resultant of these pressures is in the vertical plane of the axle and at a distance O a from O, equal to a fraction (less than one half) of the depth of the flange, that is to say, at a very short distance relatively to the radius r. For O a $= 0.59$ inch, the ratio of the distances run through would be very nearly $\frac{0.59}{19.68}$, and the increase of effort : $0.03\,f\frac{\mathrm{V}^2}{g\rho}$ only.

If, from any cause, the axle is not normal to the line, the contact of the flange with the rail no longer takes place on a segment, but on an element of the flange, at a much greater distance from the point of contact O of the tire, and the relative travel of the sliding increases in consequence.

This is what takes place, on curves, with parallel axles : the vehicle having its transverse axis directed along the radius ρ, the vertical planes of the wheel and of the corresponding element of the rail make (*fig.* 21) an angle; tang $\alpha = \frac{d}{2\rho}$, d being the extreme wheel-base. By always neglecting the

curvature of the flange and of the head (*fig.* 22), which amounts to a slight exaggeration of the distance run, and consequently the resistance, the contact is at the top of the rail and of the flange, that is to say at A, and the ratio of the distances passed through by the point A and by the vehicle is :

$$\frac{OA}{2} = \frac{\sqrt{(2r-m)m}}{r} = \text{very nearly } \sqrt{\frac{2m}{r}},$$

m being the depth of the flange, and the increase of the coefficient of traction becomes :

$$\frac{fV^2}{g\rho} = \sqrt{\frac{2m}{r}} = 0.34\frac{fV^2}{2\rho}, \text{ is then more than decupled.}$$

For $\rho = 820$ feet, $V = 32{,}8$ feet, $m = 1.18$ inch, and $r = 19\ 69$ inches, that is 6.00 lbs.

What M. *de Pambour* said was wrong (*) :

" The centrifugal force created in the passage through curves, in virtue of the velocity of the movement, may throw the waggons outwards, up to contact, and consequently cause a more or less energetic friction of the flange of the wheel against the outside rail; and the resistance produced by this cause is much more detrimental than the preceding one " (the sliding due to the difference between the distance run by the two conjoined wheels), " because the *friction is exerted through the whole of the distance run by the wheel*, and not on the difference only between the two distances run through by the two wheels. "

Which amounts to supposing the wheels to be skidded and rubbing, in the curve, by their rim and their flanges at one time.

The special resistance due to the curve is then, altogether,

$$t = \frac{f}{\rho}\left(\frac{e+d}{2} + \frac{V^2}{g}\sqrt{\frac{2m}{r}}\right),$$

the axles being without play, the tires without conicity, the line not lifted on one side; but the radius not attaining of course, the limit below which the inscription of the flanges could not be freely made, without tensions.

This expression, which is, fortunately, hardly reached in reality, is of this use that it is applied to well defined conditions, and its consequences are of value as a limit.

The increase of theoretical work due to a curve, depends only on the angle of the straight lines, and not of the radius. α being the angle subtended

(*) *Traité des machines locomotives*, page 584.

by the curve, supposed circular, its length is $\rho\alpha$, and the increase of work due to the curvature of the line is, per unit of weight of the train,

$$t\rho\alpha = f\alpha\left[\frac{(e+d)}{2} + \frac{V^2}{g}\sqrt{\frac{2m}{r}}\right],$$

a value independent of ρ. The curve connecting the two straight lines making between them the angle α (*fig.* 23) involves thus the same increase of work, whatever may be the length and the radius, always on the condition that the wheels can be freely inscribed in the curves, even the sharpest.

§ II. — Real increase of resistance.

315. Let us now return to the domain of reality. We see first that one of the terms of the limit of resistance t (314) may be suppressed : that which corresponds to the centrifugal force, a little reduced by the slight centripetal force which results, with conical tires, from the dissymmetry of the reactions of the rails (II, 179) and which is got rid of completely by the raising of the outside rail, provided the speed be that for which it has been determined.

Relation between the gauge and the radius, with equal additional effort due to the curve. The additional effort is thus reduced to $\frac{f(a+d)}{2\rho}$; ρ diminishing, the draught due to the curve remains constant if $e+d$ diminishes in the same ratio. The gauge decreasing, it is natural that the dimensions of the bodies, and consequently d should also decrease. If we suppose $\frac{d}{e} = n$, n being constant for the divers gauges, ρ will vary with equal resistance $\frac{fe(1+n)}{2\rho}$, proportionally to e. For example the radius of the line of 3.28 feet gauge for which the resistance will be the same as on a curve of 984 feet radius, with a gauge of 4.92 feet, is $\frac{3.28}{4.92} + 984 = 656$ feet. The economical advantage presented by a narrow gauge depends thus essentially on the nature of the ground, seeing that it allows the radii of the curves to be reduced without increasing the resistance. In the same way for a given gauge e, d may be as much greater than ρ itself is. It is thus that high speed rolling-stock which usually only runs, in the same system of lines, on the principal lines with flat curves, may have longer wheel-bases than the low-speed vehicles which have to run everywhere.

But it is above all for the engines that this variation of the base is

marked, particularly at the present time, because it is in the nature of things to specialize the motors by devoting them to the lines to the nature of which they are exclusively adapted. Formerly, they thought it was going as far as possible (too far indeed) by giving the *Crampton* engines, made for running at a high speed on lines of large curvature, a wheel-base of 15 feet and even 15.94 feet (II, 249); later the Northern of France admitted 17.22 feet in its four-cylinder engines (II, 257); at the present time, on the same lines, they do not hesitate to go as far as 19.69 feet, and even beyond. This is induced by two considerations : 1st, the necessity of increasing the power of the high-speed engines, the load of express trains increasing more and more, at least during a certain period of the year ; 2nd, the desire to get rid of the overhanging position of the fire-box, a position which, without necessarily compromising the stability of the engine, when the distribution of its weight is suitable, interferes however, at high speeds, with the steadiness of its running. More and more advantage is taken of the latitude allowed by the trace of the line; thus, the engines with four wheels coupled (II, 257), which perform the service of the fast trains on the principal lines of the *Mediterranean* and *Orleans* lines, are going to have a fourth axle (an addition which will be combined with a lengthening of the fire-box on the second system of lines). This comes, as we pointed out in the same number, to the type of high-speed engine on the Russian lines, with two intermediate driving-axles and two end carrying-axles (II, Pl. LXXVIII, *figs.* 14 and 15). As to that of the actual engines with six wheels, which work the most difficult lines, both as to plan and section of the same systems, they will remain what they are. The manner in which they behave on those lines, proves indirectly that the base can be increased when the conditions of the line are more favourable.

We might see in this a new example of those veerings of opinion, so frequent in railway-matters. But progress consists, altogether, in satisfying the exigences of traffic, speed and safety. At the present time, besides, the advantages of longitudinal play given to the axles, a matter which for a long time was looked on by many engineers with distrust, are no longer contested, and use will certainly be made of it for the extreme wheels of engines with long-wheel base.

In the new engines with eight wheels coupled of the South Austrian, with wheels 3.48 feet in diameter at the tread, the play, fixed at 0.20 inch for the front wheel was carried to 0.78 inch for the hind-axle. Within these limits, and for engines intended, as these are, for a very low speed, no apparatus for regulating the play is necessary (II, 332).

While in France the wheel-base is increased without hesitation, in the powerful high-speed engines with parallel axles, quite a different course is being adopted in England. Giving up the parallelism of the axles, they have not hesitated to adopt in the same circumstances, the American articulation, modified only by the means we have pointed out (II, 336). M. *J. Stirling* has further done the same thing for the four-wheeled passenger engines of the Glasgow and Southwestern line. There will be in those, instructive matter for comparison.

As to lines with very stiff curves, it is useless to repeat that recourse must be had, in one shape or other, to articulation, which is indispensable, in order that the boiler may have the power and consequently the length necessary. It has now been applied by the able engineer of the Alsatian Society of Mechanical Constructions M. *Beugniot*, to tank-engines with eight wheels, six coupled, 2.95 feet in diameter, for a 3.28 feet gauge, but designed with the view of lines with curves of 100 yards. The articulated truck is a *Bissel's* (II, 342), with two wheels, placed behind. Placed in front it would have better fulfilled the essential condition : the easy circulation of the engine through curves, especially on entering and leaving, unless the precaution were taken of giving the leading axle a sufficient longitudinal play.

The two remaining resistances are more or less reduced, the one by the conicity, the other by the slight play it is desirable to give the axles in the horn-plates; they even disappear in curves of sufficient radius for the summits of the rolling cones and the converging point of the axles to coincide with their centre.

316. *Special resistance on entering and leaving curves.* — But there is, even then, a special temporary resistance, incidental to each curve. It is not everything that the figure of *free running through* be possible. Before taking it, the axles keep during a certain time that which is suitable to the straight line; there is thus on entering a curve, a period during which the elements are preparing, adjusting themselves, so to say, to run through it as freely as possible; and this circumstance is repeated on leaving, when the axles, directed by the curves, reenter the straight line. Thence a resistance independent of the extent of the curves, and which represents, for each of them, a mean coefficient which increases, the shorter they are. Numerous curves, separated by straight lines, occasion thus a greater total resistance than a single curve of the same total extent. This special resistance, which affects the entrance and exit of the vehicles, increases if reverse curves follow on directly, seeing that the axles take the second with the reverse position suited to the first. Hence the necessity of a piece of straight of a certain lenght, at least five and twenty yards.

Rolling-stock without spring-hangers. — We have seen (II, 176), that a small amount of convergent play is sufficient, with the ordinary distance apart of axles, for them to take the radial position, even in stiff curves, 820 feet radius, for example. This amount of play exists almost always in passenger-carriages and luggage-vans. But goods-waggons, with less wheel-base, it is true, often have none; if at the same time there were any, it would be useless in vehicles the frame of which is simply laid on the ends of the springs, instead of being suspended by hangers. In the first case, the very hard friction of the slides on the springs on account of the inevitable presence of dust, renders, even with play, the axles nearly fixed, or at least renders the small possible movement more difficult and more tardy. Hangers are, rightly, in general use in Germany; they reduce without doubt in a notable proportion the resistance on curves.

A train running through a curve may, up to a certain point, be likened to a chain sliding on a cylinder with a vertical axis (Pl. XV, *fig.* 24); it would thus seem, even admitting a perfect flexibility in the articulations of the train that the inflection should always involve an increase of resistance. But if each of the isolated elements or vehicles is constructed in such a manner as to run through the curve *freely*, that is to say without more resistance than on a straight line, it is very nearly the same with the train. We have already pointed out (II, 188) that, if at the hinder end of a vehicle, the obliquity of the effort of traction tends to deviate it from the mean position on the line, in front it tends to bring it back thereto, so that the two actions perceptibly destroy each other; the reunion of the waggons in a train, is besides opposed to their irregular movements, and reduces the resistances they involve.

317. *Special resistance on curves on starting.* — But curves necessarily cause another increase of resistance to come in, especially if the frames are of great length : 1st, in backing, the pressure of the buffers, only in contact on the inside line, tending to bring the train straight and so putting the pressure of the rails against the flanges into play; 2nd, on the descent of steep inclines, the rigidity of the main being equally increased, and *a fortiori*, by the natural pressure of the waggons, especially if the train is slackened principally at the head by the engine. Starting forwards, and even more still, starting backwards, present, in effect, on curves, difficulties at times not easy to overcome. To the resistance, more or less great, opposed by a curve to a running train, are also added then, those which result, for the train at rest, of the pressure of the flanges on the inside rail.

on account of the lifting of the outside one, and also of the action at first exerted in a contrary way, for the hind-axles, of the conicity.

It is above all for engines that this latter action is serious, and particularly for coupled wheels, because it increases the irregularity of the distances run through by the two conjugate wheels. The inevitable sliding, resulting therefrom, gives the engine a marked tendency to *general slipping*, and the effort of traction which itis capable of exerting is thus much reduced, precisely in the circumstances where its maximum value would be necessary. Stoppages on the line, in curves, should thus be avoided as much as possible.

As to curves placed at the approaches to the principal stations, where all trains stop, the outside line should be lifted much less. But at stations run through without stopping by express trains only, it is desirable to take into account in fixing the amount of rise to the outside rail, of the difficulty it inflicts at starting, unless the direct trains are made to slacken a little more at those points than would be the result of the radius itself of the curve.

If, besides, the station has a reserve engine, that may be made use of as auxiliary for starting.

Let us lastly remark, that with stock which has non-converging axles, curves greatly increase the resistance caused by a side wind, on account of the displacement of the point of contact of the flange and the rail (314).

318. *Numerical examples.* The resistance due to a curve of given radius depends altogether, in each case, on a great number of elements, and particularly on details of rolling-stock construction, which have far less influence on a straight line than on a curve, and which may even annul almost entirely the special resistance due to the second. The discrepancies between the results of experiment and the simple formulæ by which it has been sought to represent them, are thus in the nature of things, greater still for curves than straight lines. It would be the more idle to seek to discuss these results, as the indication of the necessary elements is almost always more incomplete still, in the second case than in the first. The reproduction of the figures which appear the most authentic, is not however quite superfluous. Were it of no other use than to prove the necessity of new experiments, made under well defined conditions, that would still be something.

The line already quoted (II, 412 and Pl. CIII), that from *Pracchia* to *Pistoia*, which presents a long continuous incline of one in 40, and a series of straight lines and curves

of 984 feet, would be a very convenient scene of operations; a thought which naturally comes into one's mind, when the spontaneous variations of the speed of the trains are observed, according as they are on a curve, or on a straight line. One would be at first led to believe that these variations are produced by the driver or brakesmen.

France. 1st. *Old experiments.*

Trial by dynamometer, on the old Loire line. On a curve of 328 feet, the resistance of a waggon at the speed of 7.5 miles an hour, was 74.6 lbs per ton. Admitting at this speed, the resistance on a straight line to be 8.96 lbs, the resistance proper of the curve was 65.64, or more than seven times the first; but the figures of the stock, the wheel-base especially, are not indicated. The outer rail was not raised.

According to some trials made on a curve of 2625 feet, on the *Versailles* (right bank, park of *Saint-Cloud*), the resistance *seemed* to be increased by 6 per cent.

2nd. *Eastern of France. Experiments of MM. Vuillemin, Guébhard and Dieudonné* (*).

a. Passengers. Trains from ten to twenty carriages. Speed from 21.75 to 31.07 miles. Influence of the curves, inappreciable, so long as the radius is not lower than 2625 feet.

Speed. 31 miles; the influence then becomes appreciable. In a curve of 2625 feet, the resistance exceeded by $\frac{1}{20}$ th the resistance on a straight line.

b. Goods. Train of from twenty-six to fifty-six waggons : speed from 12.5 to 18.6 miles an hour. The effect of the curves is more appreciable, probably on account of the suspension without manacles (316); but the mean resistance only was measured on the sections formed in various proportions of straight lines and curves of large radius : 3280 to 6560 feet. Above this, the curves were neglected.

These curves forming less than $\frac{1}{5}$ th of the whole length, resistance = 9.92 lbs,

do. from $\frac{1}{5}$ to the $\frac{1}{2}$ do. do. = 10 66 —

do. more than $\frac{1}{2}$ do. do. = 11.47 do.

But these figures are complicated by the influence of the very variable length of the trains on the resistance per ton, either on a straight line (308) or on curves (322).

The authors estimate the resistance proper of the curve at 2.24 lbs per ton, for a radius of 3280 feet, and 3.36 lbs for a radius of 2625 feet.

Orléans. M. *Polonceau's* experiments.

Train of 35 *goods-waggons, speed of* 15.5 an hour.

Radii, feet...	$\frac{1}{0}$	6560	4593	4265	3937	3609	3280	2953	2625	2297	1968	1640	1312	984
Total effort of traction per ton.	lbs 7.16	7.16	7.28	7.50	7.84	8.29	8.65	9.52	10.30	11.20	12.20	13.33	14.56	15.90

(*) *De la résistance des trains*, pp. 44 and 45.

Subtracting from these figures 7.16, the resistance on a straight line, we have the resistance proper of the curve.

	0	0.11	0.33	0.66	1.10	1.65	2.31	3.08	3.81	4.96	6.04	7.27	8.59
	0 × 0.11	1 × 0.11	3 × 0.11	6 × 0.11	10 × 0.11	15 × 0.11	21 × 0.11	28 × 0.11	36 × 0.11	45 × 0.11	55 × 0.11	66 × 0.11	78 × 0.11

The law of the coefficients of 0.11 is evident; each of them is formed by adding to the preceding the number expressing its rank.

Thus in a curve of 6,560 — n × 328 feet radius the resistance is :

$$(0 + 1 + 3 + 6 \ldots\ldots + u - 1) \times 0.11 \text{ lbs on } \frac{(n-1)\,n}{2} \times 0.11 \text{ lbs},$$

a value applicable between $n = 0$, and $n = 12$.

We see that the resistance is very nearly doubled on a curve of 1312 feet.

M. Forquenot's experiments.

RADII.	RESISTANCE DUE TO THE CURVE.	
	Train of 40 vehicles at 15.5 miles.	Train of 12 vehicles at 31 miles.
feet.	lbs.	lbs.
3280	0.78	0.89
1640	3.13	3 36
954	8.73	9.18

These figures confirm the influence *nil*, or at least very slight, of the speed (319) on the special resistance of curves; but in this case there was another variable element : the length of the train; the resistance in question increases with it (332). In these experiments, the greatest value corresponds to the shortest train, but also at the greatest velocity, which would seem to indicate that the latter has an appreciable influence.

Experiments made on the Mediterranean.

TRAINS.	MEAN number of vehicles	RADIUS OF THE CURVES.					
		3280	2625	1640	1312	984	820
		Resistance due to the curve.					
		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Express.....	10	1.11	1.34	2.24	2.68	3.80	4.48
Passengers.....	20	1.23	1.56	2.58	3.36	4.70	5.15
Goods.....	50	1.68	2.01	3.36	4.03	5.60	6.72

The greater resistance of the goods-trains (very inferior however to that which results from M. *Polonceau's* experiments as above) is due without doubt to the double influence of the length of the train and of the absence of the spring links.

Germany.

According to experiments, now of old date, made in Hanover, the resistance due to a curve of 1542 feet, is 2.91 lbs. There is no question either, of the velocity, which at the same time has a very slight influence, or of the nature and composition of the train.

On the contrary, dynamometrical trials made on the Thuringen railway, brought out no difference between the resistances on a straight line one one hand, and the other, on curves of 1870 and even of 1480 feet radius.

On the *Steïerdorf* line, with curves of 374 feet, but with very short wheel-base, with a great amount of conicity, and (what needs scarcely be said with regard to such curves, a low speed), the *total* resistance in these curves was found to be 15 lbs. It is estimated at three and a half times the resistance on a straight line, which would thus be $\frac{15}{3.5}$ =4.28 lbs, and that of the curve, 10.75 lbs.

South Austrian. — Isolated waggons.

RADII.	TOTAL RESISTANCE PER TON (*).		RESISTANCE DUE TO THE CURVE.		OBSERVATIONS.
	Waggons with 4 wheels (**).	Waggons with 8 wheels.	Waggons with 4 wheels.	Waggons with 8 wheels.	
feet.	lbs.	lbs.	lbs.	lbs.	
620	12.27	9.70	7.06	4.66	(*) Speed 9.3 miles an hour.
748	10.73	9.05	5.51	4.00	
932	9.83	8.24	4.61	3.20	(**) Wheel base 9.84 feet.
1244	8.89	7.43	3.67	2.39	(***) Figures cited farther back (310).
$\frac{1}{0}$	5.21 (***)	5.04 (***)	0	0	

The resistance, introduced by the numerous curves of 620 feet at the Semring, has, from the outset, played an important part as means of checking the velocity on the descent, before even the application of counter-steam, the use of which is however very restricted there (222). The engines had no brake, and the drivers soon learned to utilize that resistance in managing their trains, the speed of which they did not fear accelerating on the straight lines preceding the curves. Thus, independently of the smaller amount of inclines, the trains are much easier to manage on the Semring than on the Brenner, where the curves are less close together and much less stiff.

We shall give farther on (323) a series of experiments, the special object of which was to measure the influence of the length of the train, of total equal weight, on the resistance due to the curve.

Mein-Weser.

Some trials, too soon interrupted, led to admitting that, with a sufficient rise in the outer rail, the increase of resistance due to the curves is hardly perceptible; which is nothing but quite natural if the conditions of free running through were fulfilled, and if the observation made only within the curve, took no account of the resistances at the

entrance and exit. For ever the same vagueness, the same absence of indications on the given quantities in the experiments.

The same result was arrived at, but by somewhat inaccurate means, on the line from *Altona* to *Kiel*.

Isolated waggons were allowed to run down an incline of one in 200 ending on a curve of 1503 feet radius, with play in the road of 0.71 inch, and rise of outer rail 2.20 inches; they entered thereon with a " low " speed, of course, but which is not given : the distance run through before stopping was measured, and the total mean resistance deduced from it :

1st	1 passenger carriage with	6	wheels	and wheel-base	21 ft	4.70 lbs
2nd	do.	4	do.	do.	15.43	4.93
3rd	do.	4	do.	do.	12.50	4.48

The resistance of the same six-wheeled carriage was found to be, on a straight line 4.93, that is to say the same value as on a curve of 1503 feet radius.

A six-wheeled goods-waggon, without convergent play, gave a resistance of more than 11 lbs.

In general, the contradictions presented by the results are explained, when, by chance, there has been joined thereto, the indication of all the elements, or at least the principal.

For the authors of experiments, acquainted with the stock which they are dealing, the *final* figure is sufficient : it tells all; but not much for the others.

Experiments of the same kind were made on other section of the Holstein line, from *Altona* to *Blankinser*. Two inclines of one in 200 were made use of, each followed by a horizontal. One of the inclines, as well as its horizontal was on a straight line, the other and its horizontal were on a curve of 1476 feet.

Needless to say that the velocities obtained on these sections were necessarily very low : they are not given.

I. *Straight line.*

1. Passenger-carriage from *Altona* to *Kiel*, six-wheeled, wheel-base, 21 feet	4.93 lbs
2. Goods-waggon do. to do. same base	5.60

II. — *Curve of* 1476 *feet.*

1. Same passenger-carriage	4.93
2. do. goods-waggon . . . . . new than.	11.20

In effect, with such a slight impulsion, this waggon stopped of its own accord before reaching the foot of the incline. Such an unequal influence exerted by the same curve, on the two types of vehicle, is to be explained by differences of construction. With rolling-stock suitably constructed, the additional resistance due a curve of 1476 feet, may then be very slight. However, while one waggon with four wheels and 12.50 feet base gives 4.70 lbs, another with 15.43 base, gave also 4.93 lbs, which arises no doubt from the axles having play in the one case and not in the other; but which proves chiefly that one must be in no hurry to draw inferences from experiments of this kind.

Eastern of Saxony. Experiments made by Mr. *v. Weber*, in 1860. The mode of expe-

riment consisted also in increasing the space run through, in curves, by isolated waggons which entered thereon with a low known velocity.

WAGGONS.	WHEEL-BASE.	RADII OF CURVE.				
		ft. 1824	ft. 1486	ft. 1136	ft. 745	ft. 558
		Additional resistance due to the curve, the resistance on the straight line being 1 :				
	feet.					
Passengers 6 wheels.....	20.96	1.91	3.08	3.68	5.79	6.00
do. 4 do.	14.99	1.56	2.50	3.04	4.90	5.63
Goods..... 4 do.	12.00	1.39	1.95	2.30	3.05	4.16
do. 4 do.	11.68	1.41	2.21	2.66	3.00	4.39

Some observations on the Westphalia line gave the following results, the resistance on a straight line being again taken as unity :

RADII.	TOTAL RESISTANCE.	RESISTANCE DUE TO THE CURVE.
4921	1.125	0.125
4324	1.168	0.168
3087	1.200	0.200

According to M. *Schmidt* (*) the experiments made in Austria up to 1856, led to the following values, always in function of the resistance on a straight line :

RADII.	TOTAL RESISTANCE.	RESISTANCE DUE TO THE CURVE.
feet.		
3.280	1.176	0.176
1.640	1.238	0.238
820	1.378	0.378
492	1.526	0.526
328	1.757	0.757
246	2.009	1.009
164	2.624	1.624
82	6.293	5.293

According to the same engineer, these curves would be equivalent respectively, to gradients of

1001 | » 769 | » 500 | » 357 | » 250 | » 187 | » 116 | » 35.7

(*) *Zeitschrift des Oesterreichischen Ingenieurvereins für* 1857.

or in other terms, these figures would represent, in fractions of the weight of the train, the resistances due to these curves; whence would result the value of the resistance on a straight line and a horizontal.

x being that resistance, and consequently $0.176\,x$ the resistance due to a curve of 3280 feet, we have $0.176\,x = 0.00099$, whence $x = 0.0056$, or 12.54 lbs per ton.

The other values give $x = 12.32$ and 11.87 lbs; a considerable resistance, if, as is probable, the speed, not given, was very low.

In principle, this expression of the resistance due to a curve, in function of the resistance on a straight line, is inadmissible, seeing that the first is very nearly independent of the speed, while the second depends on it; the ratio in question has only any meaning, when the speed is low enough to have no appreciable influence on the resistance on a straight line.

Mr. *Lloyd*, engineer of the line from *Santiago* to *Valparaiso*, has made known, in a paper inserted in the minutes of proceedings of the Institution of Civil Engineers (*London*), the results of some experiments made on that line, with a 5.5 feet gauge; but the weakness of the dynamometer which he had, only allowed of his dealing with one vehicle.

On straight line and ascent in 50, 56 lbs per ton On same gradient curve of 600 ft 71 lbs	Speed not given, doubtless very low.

The resistance due to the curve was thus 15 lbs; for the ordinary gauge it would thus be nearly $15 \times \frac{4.7}{5.5} = 12.99$ lbs.

Mr. Lloyd has also ascertained that, on a horizontal, the resistance on a curve of 1000 feet (5.5 feet gauge), is double that on a straight line, when it follows that the resistance due to that curve is 11.2 lbs, value of the resistance on a straight line and horizontal (56-44).

These two values : 15 and 11 lbs, do not satisfy the law of the inverse proportionality of the resistances to the radii : 600 and 1000 feet; a very simple but not less inexact.

§ III. — **Indirect estimate of the resistance due to curves.**

319. The Northern of Austria line has collected during a long period (since 1855) very complete observations on the depreciation of rails of various sorts : wrought-iron, puddled steel, *Bessemer* steel; of different sections, and placed in various conditions of line, as to plan and section, of the gross traffic (total number of tons) and types of the rolling-stock, particularly the wheel-base.

From these observations, and the graphic traces which have been deduced from them, the engineers have drawn this important conclusion, that with

a weight reduced in the inverse ratio of the elementary prices, *Bessemer* steel has always a very superior durability to that of iron. So that, at the present time, and whatever may be the conditions of traffic, the use of iron would never be warranted. But it is not a question of this point here.

The wear of rails is a complex effect, the resultant of a great number of causes, and curves evidently have their share therein. In order to establish the value of a given rail, that is to say, the total number of tons the passage over it of which it can stand before becoming unserviceable, the influence of the variable conditions of the line must be set free, and the whole brought into a comparable shape : the *quantum* of the running on a normal line, that is to say on a horizontal and a straight line. In order to effect this reduction, the North Austrian company has deduced from its observations the coefficient by which should be multiplied the tonnage of a rail placed in curve, on an up or down incline, so as to get its absolute tonnage, that is to say, on a *normal line*.

Curves.

Radii.....	$\frac{1}{0}$	feet. 6562	feet. 5906	feet. 5249	feet. 4593	feet. 3937	feet. 3280	feet. 3625	feet. 1968	feet. 1640	feet. 1312	feet. 984	feet. 656
Coefficients....	1	1,15	1,17	1,19	1,21	1,25	1,30	1,37	1,50	1,60	1,75	2,00	2,50

Gradients and inclines.

One in :.....	1000		900		800		700		600		500	
Inclinations.....	Up.	Down.	Up.	Down.	Up.	Down.	Up.	Down.	Up.	Down.	Up.	Down.
Coefficients	1,28	1	1,31	1	1,35	1	1,40	1	1,47	1	1,56	1
One in :.....	400		300		250		200		150		100	
Inclinations.....	Up.	Down.	Up.	Down.	Up.	Down.	Up.	Down.	Up.	Down.	Up.	Down.
Coefficients.....	1,70	1	1 93	1	2,12	1,12	2,40	1,40	2,87	1,87	3,80	2,80

That is to say a given amount of running 1, on a straight line, and horizontal, produces on the rail, in the curves and on gradients indicated, the same destructive effect as that amount of running 1 multiplied by the

respective coefficients; or again, that the wear increases in these curves by 0.15, | 0.17, | 0.19..., and on these gradients, by 0.28, | 0.31, | 0.35..., of its value on a straight line.

The lines of the Northern, the flattest of the Austrian system, did not furnish the necessary elements for prolonging this second table beyond an inclination of one in 100; of course, it only deals with railways with double lines.

The influence of these flat gradients on the deterioration of the rails seems very considerable.

As to the down inclines, their influence, nothing at first, only becomes manifest from the point where the action of the brakes commences to be necessary, and it increases afterwards with that action.

In fact, so long as the brakes have not to act, the down inclines ought to be favourable to the durability of the rail, because they reduce a serious cause of deterioration, the tangential effort of the driving-wheels and especially the slipping. The corresponding coefficients ought thus to be less than 1.

By bringing together curves and gradients to which nearly equal coefficients correspond (1.30 and 1.31 | 1.37 and 1.35 | 1.50 and 1.47 | 2 and 2.12), we see that, as regards the deterioration of the rails, curves of 6562 feet, | 2624 feet, | 1969 feet, | 984 feet, would be equivalent to gradients of one in »909, | » 800, | »599, | »250.

Admitting, which is plausible enough, the increase of wear in the rails, either on curves or on gradients, may serve as a measure of the increase of resistance which they involve, it would result that this increase of effort would be respectively, for the above radii 2.43, | 2.76, | 3.68 | and 8.82 lbs per ton.

The statements have allowed also, the appreciation, up to a certain point, of the influence of the wheel-base d, on the deterioration of the rails; these would be nearly proportional to d^2, and it would be the same for the frictions of which that deterioration is the effect. But a more solidly established experimental proof, more direct, would be necessary to make that law accepted.

The above coefficients, without taking into account the uncertainty incidental to their mode of determination, can only be nearly exact for the lines which have supplied the elements for them. They would be more or less different for other lines, and it is precisely for that, that the comparison of their values would be very instructive.

How many useful and doubtless unexpected consequences, would spring

out of the observations which have been collected on the different systems of lines, and above all of those which might be!

§ IV. — Empirical formulæ.

320. In England, use is often made, for the 4.7 feet gauge, of these two very simple empirical formulæ:

1st. $\frac{1}{r}$ which gives, in fraction of the weight of the train, the resistance due to the curve of which r is the radius in yards.

For a curve of 275 yards, for example, $\frac{1}{r} = 0.0036$.

For a radius of 200 yards, $\frac{1}{r} = 11.2$ lbs per ton, instead of 13, the figure resulting from M. *Lloyd's* experiments (317).

2nd. $\frac{10\,000}{r}$, which expresses the resistance in pounds per ton of the train, the radius r being in feet. For $r = 600$, it gives 16.7 lbs per ton, or 50 per 100 more than the preceding one.

3rd. Professor Rankine gives, for passenger-carriages: $\frac{1.4}{r \text{ miles}}$ as expressing the resistance, in pounds per ton.

For $r = 1$, it gives 1.4 lbs, while with the usual rolling-stocks the resistance corresponding to so long a radius is inappreciable.

On a curve of 0.113 the resistance is 13.89 lbs.

According to Professor Rankine, the conicity, which diminishes the resistance on a curve, increases it on a straight line. It is a question of amount. If the conicity exceeds a certain limit, it is likely that the resistance on a straight line increases, especially if the speed is great. But it is certainly not so for the slight amounts admitted in Europe: $\frac{1}{20}$th and even $\frac{1}{16}$th.

The Institution of Civil Engineers (London) has an excellent practice, by the way. In the discussion, always interesting and often very profound, of the papers laid before it, it in no way considers as idle, that principles, even those most generally accepted, should be brought in question. One of the points which most frequently comes up is the solidarity of wheels and axles. The free wheels seem to gain ground, at least in theory, and they are receiving some applications, on a small scale, it is true.

The raising of the outer rail does not escape the criticisms. Mr. *J. A. Longridge* has undertaken to examine into them (*), but he has done so from an imperfect

(*) *Minutes of Proceedings*, 1870-71, vol. XXXI, p. 383.

point of view, and resting on the example, rather inconclusive however, of the temporary line over Mount-Cenis, with central rail.

4th. From divers experiments made in the United States, Mr. *Latrobe* has deduced the expression $\frac{0.578}{r \text{ miles}}$, giving values nearly three times less than the preceding.

According to the same engineer, the additional resistance due to a curve of 100 feet radius, is for American stock 30 lbs per ton, and it varies inversely as the radius.

Experiments made on the *Erié* line have led to this rule: the special resistance is 0.5 lb for each degree subtended in the curve by an arc of 100 feet in length.

Let us apply this rule to the 100 feet curve cited by Mr. *Latrobe;* the arc subtended in this curve by an arc of 100 feet, is $57°,3 = 57°18'$. The resistance is thus: $0.5 \times 57.3 = 29.5$ lbs, a figure in accordance with Mr. *Latrobe's*. Which however perhaps arises simply from the fact that the two rules have been derived from the same observations.

According to another rule, proposed by Mr. *Molesworth*, the resistance due to a curve is, for each degree subtended by the train, $\frac{1}{100}$th of the resistance on a straight line and horizontal. The latter, at the velocity of 20 miles an hour is estimated at only 12 lbs. The increase of resistance of a train passing through a curve of 100 feet radius, and the same length, would thus be $\frac{1}{100} \times 12 \times 57.3 = 6.96$ lbs, that is to say only one quarter of Mr. *Latrobe's* figure.

In general, English engineers complain that their American colleagues estimate the resistance due to curves far too low; but with such different rolling-stock, having for feature, the one rigidity, the other complete flexibility, a great inequality in the resistances explains itself.

5th. An expression of the same form $\frac{0.77}{r}$ (r in metres) proposed by the engineers of the Brunswick lines as representing the resistance in a fraction of the weight, gives intermediate values: or for 600 feet radius, 9.40 lbs.

The velocity does not figure in these formulæ. In effect, in the middle of discrepances which are explained by the diversity of the details of construction, what comes out of the experiments taken altogether, is the very slight, if any, influence of the velocity on the resistance proper of a curve. As long as the centrifugal force is destroyed by the lifting of the outer rail,

it is not to be seen how the velocity could come in. Its influence is, on the contrary, quite simple, if it deviates more or less from that which corresponds to the amount the outer rail is lifted, and there still is a certain margin, resulting from the transverse friction of the tires which has to be overcome, when the inscription is done with a certain amount of play in the flanges, in order to bring them into contact either with the outside rail, or with the inside one.

If reference be made to the experiments of the engineers of the Eastern of France, the *resistance proper* would diminish when the velocity increases: that can and ought to be, as long as the increasing velocity remains inferior to that corresponding to the lifting of the rail, and for which the resistance is a minimum. But as it was a question, in these experiments, of curves of large radius, the fact, supposing it well established, may be also attributed to a cause which comes in to mask the resistance, then very low, which is proper to them. One of the causes of the increase of resistance, with the velocity, on a straight line, is the serpentine movement which the vehicles take, and which is more and more marked. On a curve, this movement is reduced, or ceases. The resistance which it involved is then replaced by that which corresponds to the curve; as long as the latter is low, on account of length of the radius, it can only be equal or even inferior to the first; so that, from a certain value of the increasing velocity, the total resistance may be the same on a curve of large radius, as on a straight line, if not even less.

321. *Remarks on extreme traces.* For local lines, where an economical construction is imperative, curves of 820 feet have been admitted (Charente, Loire); the third goes down even to 656 feet. The ordinary limit is 984 feet, but while quite accepting it, sometimes it is departed from at stations, going down to 656 feet (Ain). The figure of 328 feet had even been admitted for the Allier, in the trial lines run in 1866. If difficulties or special requirements near stations, can warrant such exceptions, engineers should not overlook that very sharp curves in the neighbourhood of stations may involve difficulties and greater loads that anywhere else, on the working, on account of the starting.

For these secondary lines, the example of some great lines, on which a radius of 656 feet and even below has been gone to, should no longer be followed.

In order to get up great heights and pass over the ridges in very tortuous mountain regions as in the Cevennes for example (line from *Alais* to

Brioude), it was necessary, while allowing the necessity of enormous works both masonry and earthwork, which bring the cost of the mile of single line to from £ 45 000 to £ 51 200 per mile, to also accept curves of 656 feet. The line was only possible by forcing every element : works, gradients (1 in 40) and curves. There was nothing to hesitate about, provided.... that the line was really necessary, and that its turn had come.

The creation of the Grand Central system was an episode well known, perhaps however not sufficiently, of the history frequently unsatisfactory, of a period still recent. This system was judged *necessary*, in effect, but necessary to certain interests which, ably directed, only required, in order to reap the harvest, the passing fact of its legal existence. They had come a little late, the good lines were taken. The object once attained, there was only one thing to do, and the soonest possible: to liquidate by dismemberment, an operation which its promoters had never had the simplicity to consider productive in itself. Properly cut up, the Grand Central was divided among the neighbouring systems, which were obliged to accept that legacy, of course for very necessary compensation. The exchanges of conditions and advantages, the almost inextricable entanglement of reciprocal obligations (including that division of the spoil, in which vexed minds would only see a deceiving mirage) which ended, by degrees, in definitively bringing down on the country the responsibility of the financial position of the companies, form the characteristic feature of the constitution of our railway-*regime*; a regime which is neither working by the State, nor working by the companies responsible for carrying them on, but which, after all, is, perhaps none the worse for that, clear and absolute solutions seeming little appropriate to our actual temperament.

It is thus, however that may be, that the Cevennes line, that of the Livron have prematurely come into existence. They render some services without doubt, but at what price! Now we know. These lines which were required by no interest really urgent, have long been in existence, and the railway on the right bank of the Rhône, between *Lyons* and *Marseilles* waits, and probably while wait long still.

Nothing can more properly, at least, edify engineers and all those who are called upon to study the questions of railways as to the seriousness of extreme traces, than the example in question. The repulsion with which they, so to say, inspire the traffic, which does not hesitate to make long detours to avoid them, speaks more forcibly than all discussions. And we cannot too strongly advise those who may be inclined to believe that

curves of 656 feet with gradients to help them, do not exclude cheap working, to meditate on the lesson herein contained.

322. *Examples taken from some industrial lines.* It is necessary also, especially in the matter of curves, to be on one's guard against certain more unpretending examples, from which by that very fact, one is sometimes apt to draw dangerous conclusions.

In a note on railways of local interest, M. *Varroy* (*) *ingénieur des Ponts et Chaussées*, cites the following fact:

" The firm of *Wendel* worked, from 1863 to 1865, a branch of six miles long, from *Hagondange* to *Moyeuvre*, with a curve of 295 feet radius, forming nearly a quarter of a circle.

The Eastern of France waggons, drawn by special engines (at first of 8 tons and two axles, then of 27 tons and three axles), ran through that curve without the drivers requiring to avail themselves of *all the acquired velocity*. They slackened, on the contrary, in order to avoid running off the line. When the rails were wet, the waggons showed no *extraordinary* resistance, when the rails were dry, the resistance became appreciable. M. *Aweng*, director of the *Moyeuvre* works, has assured us, that one day a train composed of forty-two waggons, one third of which were full, had passed through, without apparent difficulty or trouble, the curve of 295 feet. It was a train weighing 340 tons gross, and nearly 980 feet long. "

It would seem that the consequence to be drawn from the foregoing, is, that a curve of 295 feet and 462 feet in extent, would be admissible for such rolling-stock as that of the Eastern of France, that is to say with a wheel-base from 7.88 to 8.86 feet, without spring hangers, for engines with six wheels coupled, and for trains 980 feet long.

But in reality the facts cited prove only one thing : the great excess of the power of the engine, very badly utilized therefore outside the curve of 295 feet. M. *Aweng's* observation touching the fact that took place « one day » seems perfectly to indicate that it was an accidental occurrence, produced by a conglomeration of favourable circumstances, and not without exciting some astonishment. It is scarcely to be doubted that on that day, and probably always, the curve was run through mainly by means of the acquired velocity, and that the slackening of which M. *Varroy* speaks was chiefly the consequence of the increase of resistance introduced by the curve. We ought to know what were the velocities before and after the curve.

(*) *Note sur les chemins de fer départementaux de la Meurthe*, pamphlet 8vo, 1866, p. 43 and 44.

Nothing is assuredly more natural, when the position of a curve allows the inertia to be made use of to pass through it, to take advantage thereof as is done for short gradients. This consideration may even lead to a curve being accepted, which, at other points should be rejected. But these particular cases cannot be brought forward as a general justification of curves of the same radius, and as a proof of the smallness of the resistance they engender. Account must be taken besides, of the more or less probable occurrence of a stoppage, and of a starting in the curve.

Moreover, M. *Varroy* adds :

" When MM. *de Wendel* altered the junction of the *Moyeuvre* line with the *Thionville* one, they carried the radius of that curve (295 feet) to 656 feet. "

A very wise step, which the nature of the ground readily admitted of, but which was indispensable from the point of view of resistance, but also and mainly in the interest of the axles which such stiff curves could not fail to strain remarkably, and to predispose them to fracture (II, 81, 85, 298 at Additions, pages and following). Let us add that the line from *Hagondage* to *Moyeuvre* offers numerous curves of 490 feet. If, as the author of the note says,

" these curves are considered as offering no real hindrance appreciable at the speeds in use of from 10 to 12 miles an hour, "

why not have remained at that limit, instead of altering the curve of 295 feet to 656 feet ?

If we agree with the author that

" this line is a very interesting example to study for the construction of railways of local interest. "

it is because it seems to us to lead to very different consequences, very different from those which suggested this investigation to him.

While in Europe the extreme limit of the radii of curves goes down at the present time, for great lines on very difficult ground, to 656 feet, it is very nearly also that limit also they have stopped in the United States, but after having long admitted much smaller radii. Thus the most important section of the Pensylvania line, that which crosses the Alleghanies between *Philadelphia* and *Harrisburg*, executed under extreme conditions of trace, has been almost entirely reconstructed, by reducing the mean inclinations to one in 55, and carrying the radii of the curves to 720 feet (*). The

(*) *Report of the Investigation Committee of the Pensylvania Railroad Company*, 8vo, *Philadelphia*, 1874.

same point has thus been arrived at : in Europe, by admitting that hitherto far too heavy concessions had been made to the requirements of working; in America, by showing that they had on the contrary been unreasonably hardly dealt with.

§ V. — Influence of the length of the train on the amount per unit of weight of the resistance due to curves.

333. We have seen (308) that on a straight line, the resistance to traction increases, with equal weight, with the length of the train.

We have already said (II, 263) that it is the same on curves, and the influence of the length seems to be even more marked thereon; it is principally on the Semring line, a field of observation, highly satisfactory as regards curves of such radii, that the fact was ascertained. The death of the engineer who directed the dynamometrical experiments, caused the details to be lost sight of; but, at least the abstract of the observations remained. M. *Gottschalk* has been good enough to have them looked for, and to communicate them to me.

COMPARATIVE TABLE

Of the trials made with long and short trains of the same weight on the Semring *curves.*

RADIUS of the curves.	TRAIN OF 26 WAGGONS WITH 4 WHEELS.		TRAIN OF 13 WAGGONS WITH 4 WHEELS.		
	Train of the 14th of Sept. 1863 from Gloggnitz to Semring. — Weight of train 195.6 tons.	Train of the 15th of Sept. 1863 from Gloggnitz to Semring. — Weight of train 195.6 tons.	Train of the 16th of Sept. 1863 from Gloggnitz to Semring. — Weight of train 193.4 tons.	Train of the 17th of Sept. 1863 from Gloggnitz to Semring. — Weight of train 193.4 tons.	Train of the 16th of Sept. 1863 from Mürzuschlag to Semring. — Weight of train 193.4 tons.
	Total resistance in lbs per ton.				
feet.	12.56	12.25	12.88	11.78	
	12.36	14.04	12.00	11.98	
620	12.39	14.42		12.07	
		13.73		11.62	
		13.88		11.69	
		13.55			
	13.24		12.00		
	9.92	12.02	10.41		
870	10.98				
	9.05	9.94	10.98	10.46	10.10
	9 36	10.23	10,68	9.54	9.96
	12.18	10.05	10.93	10.10	9.88
932	8.96		9.56	9.54	9.54
	9.05		9.81		9.32
			10.41		
	10.98		10.19		

Thus by doubling the number of the waggons with a total weight of train the *total* resistance per ton increased :

In the curves of	620	feet from	12.00 to 13.24	lbs or	10.3	per cent
do.	870	—	10.42 to 10.97	or	3.4	—
do.	232	—	10.19 to 10.43	or	7.7	—

Like those which we quoted farther back, these experiments were made at the velocity of 9, 3 miles an hour. The resistance on a straight line, and on a horizontal, differed thus very little from 5.22 lbs (310).

There is thus for resistance on the curves :

RADII.	TRAIN OF 26 WAGGONS.	TRAIN OF 13 WAGGONS.	DIFFERENCES.
620 feet.	13 24 — 5.22 = 8.02 lbs.	12.00 — 5.22 = 6.78 lbs.	18 per cent.
870 »	10.97 — 5.22 = 5.75 »	10.42 — 5.22 = 5 20 »	10.8 »
932 »	10.43 — 5.22 = 5.21 »	10.19 — 5.22 = 4.97 »	15.7 »

" The journey from past 172 to past 185 (kilometres) on the *Paris* and *Strasburg* line ", say the authors of the paper *on the resistance of trains* (page 44), " presents a multiplicity of curves the radius of which *goes down* to 32.80 feet.

" On this section, trains of from 35 to 50 waggons required on the average an extra-effort of traction of 2.2 lbs per ton, over the trains only containing from 25 to 30 waggons. "

But in order that the difference be attributed solely to the difference in the lengths of the trains, it would be necessary that the trains should be of the same length.

§ VI. -- **Means of reducing the griping of the engine-flanges on curves.**

324. *Use of water, injected on the rails or on the flanges, in order to facilitate the passage of engines through curves.* The resistance added in curves, being caused by the friction of the flanges against the rail, it is natural to seek, in order to reduce it, to act on the coefficient of that friction. The difficulty is to lower this coefficient without reducing it for the tires, and even increasing it at need (II, 282).

Long ago, with this object, the attempt was made to employ water injected either on the edges of the rails (II, 420, *Dom Pedro* line; line from *Santiago* to *Valparaiso*), or on to the flanges of the wheels.

Experience proves that by throwing a jet of water on the rails on curves,

griping is greatly reduced, as is evidenced by the grinding of the flanges. This fact seems difficult to reconcile with that, well established however (II, 200, 202), of the equivalence from the point of view of adhesion, of these two extreme states : *dry* rails, *wet* rails.

As in curves it is only a question of the edges of the rails, it might be admitted, that these edges, almost vertical, do not remain wet, like the almost horizontal top of the head, and that they only retain the very thin film which constitutes the moist rail.

The injection on to the rails, in front of the engine-wheels, is applied on the small line which has just been opened for traffic between *Zürich* and the *Utliberg*. The engines, with six wheels coupled and 6.56 feet wheel-base, run easily through curves of 490 and 470 feet radius. The head of the rail being wet, the adhesion is in no way affected, so that no use is made of sand, although the section seems at first sight to require it. It is true that this exclusion of sand is systematic, and perhaps on scarcely sufficient grounds.

On the Central Swiss, where the injection of water is equally practised, it is done, not on the rails, but on the wheels (front) of the engines, the flanges of which used to wear very rapidly on curves. It is not sought, which would at the same time be difficult in throwing a jet of water to a distance, to hit the flanges only; the tire itself is equally wet on its whole surface. That being the case, if on the one hand we conceive that the flange arrives at contact with the rail suitably moistened, it seems on the other that as the tire arrives in nearly the same state on the top of the rail, the adhesion should be effected. This may partly explain why the use of sand (even more indispensable than before the injection) is always in force on the Central Swiss, while in the *Utliberg* line, with direct injection on the rail, recourse is not had to this operation; but it is perhaps also the consequence of the difference of velocity, which is greater on the Central Swiss.

As the opportunity presents itself, it is desirable to add a few words touching this little line, the construction of which is more recent than the publication of the second volume of this work :

Gauge of 4.70 feet; length 6.58 miles; height surmounted 1312 feet; mean inclination one in 23; but the gradients reach one in 15 and one in 14 for 0.50 miles; the sharpest curve, 470 feet radius, is on a gradient of one in 16.

In an essay quoted by M. Mallet (*), the engine-tender weighing from 24 to 25 tons, with wheels 2.99 feet in diameter, and wheel-base of 6.23 feet, with 786 square feet of

(*) *Society of Civil Engineers* of *Paris*, *Meeting* of the 7th of May 1875. — Communication from M. *Mallet*.

heating-surface and with a pressure of 12 atmospheres (effective), pushed in front of it three waggons weighing from 25 to 28 tons, the speed varying from 8 to 10.5 miles an hour.

Allowing, so as to take the curves and the smallness of the wheels into account, 13.23 lbs per ton for the resistance of the train not including of course, the resistance of the machinery, the effort of traction at the circumference at the driving-wheels was $(24.5 + 28) \times 2240\ (97 + 13.23) = 2.625$ tons, or $\frac{1}{9.3}$ of the mean adherent weight 2,45 tons. The adhesion was thus amply sufficient.

The velocity on the descent is regulated, as at the *Rigi*, by an air-brake, with the injection of cold water into the cylinders.

If this trial represents the conditions of running adopted, it is clear that there was not even occasion to put the question which, as it appears, was at first raised, of the use of the rack. When a velocity of over seven or eight miles an hour is desired, there is no reason for the rack; the adhesion is sufficient. It does not cease te be so if, in order to increase the load drawn, and consequently the effort of traction, a very low speed be accepted, as at the Rigi. At the same time, a very low speed on the gradients implying the rack, was rejected by the very conditions of the trace. The length, relatively considerable and with flat gradients, comprised between the town and the foot of the mountain, would have had to be worked by an engine with simple adhesion.

M. Mallet says, on the subject of some trials made on the new line with a rack from *Arth* to the Rigi, and in which the speed reached 8 miles an hour :

> " These trials had chiefly for object to ascertain the *possible* velocity of translation of these engines, an interesting question, for *an opinion widely spread is that the engines with a rack cannot exceed a velocity of three or four miles an hour.* "

The engines with a rack *can* evidently (leaving the question of prudence on one side) run at the speed which corresponds to their dynamic effect and the greater or less effort of traction required from them. But what is true, is that these engines *ought* only to run at a very low speed, that is to say at a speed low enough for the adhesion not to be sufficient. Beyond that limit, the rack with all its concern would only be a costly piece of nonsense.

325. *Remarks on engines with gearing, or in general, with intermediate driving-shafts.* In spite of the unusual amount of the rates of inclination, the *Utliberg* engines have direct transmission. This is the natural conse-

quence of the speed adopted, which is relatively considerable. They did nothing but reduce the diameter of the wheels as much as possible; and then, at that speed, the number of turns of the wheels, and consequently the beats, are sufficient to insure a powerful production of the boiler (118, and II, 199).

The use of an intermediate shaft transmitting the movement of the pistons to the driving-wheels by means of gearing, is looked on at the present time by some engineers, with an amount of favour which seems little justified. It is, once more, a question of speed. If, by reducing the diameter of the driving-wheels as much as the general conditions of the engine will permit, the free play of the connecting-rod ends, etc., the number of turns, corresponding to the velocity adopted, is decidedly too low for the evaporation, there can be no hesitation. This was the case at the Rigi, for example. But it can scarcely be conceived that such a complication would be admitted for engines (as those of a local line) of which the diameter of the driving-wheels notably exceeding 3.28 feet, could be reduced.

Without doubt the *intermediate shaft* has in itself, and independently of the consideration of speed (which can alone warrant and require gearing), advantages which we have pointed out (II, 251). But they are exaggerated when the complication it involves is so easily admitted, even without gearing. It is only when the latter is necessary, that its inevitable consequence, the intermediate shaft must be accepted. Otherwise, the advantage of placing the machinery of a locomotive in the conditions of a stationary engine, installed on a perfectly unyielding foundation are purchased too dearly.

Let us cite, on this subject, a new attempt at a locomotive with gearing. At the meeting of 1875 of the British Association at Bristol, an inventor, Mr. *Handyside*, brought under its notice an engine for steep gradients : it is a locomotive with ten wheels coupled, carrying two cylinders behind arranged very nearly as those of M. *Carels* (174), and which drive by gearing a windlass installed under the foot-plate. When the load is too heavy for the engine to draw it directly, the engine uncoupled runs up alone the whole or only a portion of the gradient, and anchors itself to the rails by means of grapplings analogous to the jaws of Jowler's pulley (II, 215); a chain wound round the pulley is undone and hooked on to the train, which is drawn by the engine, as a stationary engine. This only a variation of arrangements tried many times, and inadmissible in the working of railways, admitting that they may, strictly speaking, find an application in the construction of works.

The engine in question was tried on a gradient of one in 12.5 (*Avonmouth* Dock works). But the breakage of one of the parts put an end to the experiments almost at the beginning.

326. *Greasing the flanges of the wheels, or the edges of the rails.* It is not only to water, that recourse has been had for facilitating the passage of vehicles, and particularly of engines, through curves, but also to oil. To apply regular greasing to the flanges would seem dangerous; the tire is so close; what would become of the adhesion? Long ago however, in the United States they succeeded in managing this (II, 420. Passage of the Blue Mountains by Mr. Ellet). A little before the entry into the curve, a lever applied a small sponge imbibed with oil, against the flange, and kept it there during the passage through the curve. The same expedient is in use in Chili.

One of the engines exhibited at *Vienna* in 1873 (Pl. XV, *fig.* 25) offered a surer and simpler means. The oil is replaced by a block of very hard tallow, *s*, *s*, enveloped in a sheet of tin, pressed by a spring, to the required extent, against the flange. In rainy or foggy weather, the friction of the wet tires does not take off any tallow perceptibly. The action recommences as soon it is necessary, that is to say when the flange is dry.

On the line from *Baltimore* to the Ohio (II, 421. Temporary crossing of the Alleghanies, Mr. *Latrobe*), the oil was applied to the edge of the rail.

Altogether, these means seem efficacious; and they should not be neglected, in the requirements of actual traces. Perhaps it might be possible to charge the permanent way men with the duty of keeping the edges of the rails greased on certain curves. The success of the use of fatty matters applied, either to the flanges, or to the rails, might at the same time depend on the nature of the ballast; grains of fine sand or dust would form with grease or oil, a sort of paste not very lubricating.

327. In the number of extreme traces mentioned in chapter XIII, vol II, the new branch line from *Poli* to *Tiflis*, could not be included. This line connects the Black Sea with the line from *Tiflis* to *Reseld*, and consequently with the Caspian, by crossing the spurs of the southern flank of the Caucasus. The culminating point, at the height of 3200 feet, is reached by means of gradients of one in 22, for 5.5 miles on one side of the ridge, and the radii of the curves, often reverse, with tangents of only three lengths of a waggon, go down 525 feet.

The locomotive superintendent, M. *Sternberg* has made known some interesting facts, which characterize the influence of such a line, and particularly of the curves, on the conditions of traction.

The line is divided into three sections :

1st Gradients (*up*) one in 70 at most, one in 100 on the average, curves of 1368 feet at least
2nd do. one in 45 do. do. 525 do.
3rd do. one in 22 do. do. 3445 do.

Types of the engines :

A. Passenger ; tank-engine with four wheels coupled, and articulated leading-truck ; wheel-base on the parallel axles 7.15 feet; weight, 38 tons; adherent weight, 22 tons; effort of traction at 8.5 ats, 3.74 tons; do. at 9.5 ats (a pressure authorized by exception), 4.10 tons; adhesion 3.00 tons (with sand).

B. Goods : tank-engine with six wheels coupled and articulated leading-truck; rigid wheel-base, 10.83 feet; weight, 56 tons; adherent weight 34 tons; effort at 8.5 ats., 5,90 tons; adhesion 4.00 tons.

C. Two articulated trucks (*Fairlie type*); wheel-base 8.0 feet; weight 60 tons; effort at 8.5 ats, 8.70 tons; adhesion 7.50 tons.

Experience proves : 1st, that the type A can run comfortably in the second section. The engines B, even with the leading-axle uncoupled and with play, greatly destroy the line; and, contrary to expectations, it was the same thing with the *Fairlie* engines (C.).

The latter at first seemed to be the only one to suit the third section, on which all that the other can do, on those gradients of one in 22, whenever the rails become greasy, is to draw themselves.

For the determination of the loads, the resistance has been estimated at :

On the 1st section (mean speed 12.4 inches) at 20.16 lbs a ton, or 42 lbs on one in 100
do. 2nd do. 8 do. 33.60 do. 82 45
do. 3rd do. 6 do. 22.40 do. 121 22

On the descent, the speed varies from 7 to 9 miles an hour. All the engines, besides counter-steam, have a special steam-brake, and all the waggons a hand-brake.

Up the one in 22, the *Fairlie* engine drew, according to the reason, five to six waggons of 15 tons, or 80 tons, and in all $80 + 60 = 114$ tons; corresponding resistance measured on the driving-wheels, $114 \times 121 = 13.823$ lbs $= 6.27$ tons.

Experience confirmed these figures from the commencement, and consequently the values admitted for the resistance. But it is quite another thing with respect to the *Fairlie* engine, the growing reputation of which, kept up by an inordinate amount of publicity, seems to have had rather a severe blow in the *Caucasus*. Considering all its complication, the frequent derangement of the flexible steam-pipes, the small amount of resistance offered by that frail union of parts, not solidly connected together, to shocks, even very slight, one comprehends better the utility, to say no more, of the installation of the engine on one single base, solidly constituted and connecting all the organs. In spite of its total adhesion and its flexibility, the *Fairlie* engine, such as it is at least, and without generalizing the consequences of a particular fact, does not appear to be the locomotive for gradients and curves, that is to say, a mountain-locomotive.

Thus it is sought, on the line in question, and in spite of the difficulties of the line, to return to the old principle, that of parallel axles. An engine, with eight wheels coupled capable of exerting, under a pressure of 10 atmospheres (absolute), an effort of traction of 8 tons, has been designed; with wheels of 3.28 feet in diameter, it would have a wheel-base of 10.66 feet, but tempered by the longitudinal play given to the extreme axles, and at the same time a little less than that of the engines with six wheels coupled (type B). As the principle has been started with, that curves of 525 feet radius admit of a wheel-base of 7.48 feet, we should expect that the engine in question would not suit the second section, but it is especially in view of the third that it is devised.

BOOK SEVENTH

POWER AND USEFUL EFFECT

OF

THE LOCOMOTIVE.

CHAPTER .

POWER OF LOCOMOTIVES.

328. It is in the nature of things that locomotives, those especially which do the work of heavy lines, should develop a very variable amount of work: sometimes slight, none, even negative down inclines, sometimes, on the contrary, on gradients of moderate length, superior to that which they could keep up permanently, or simply for a prolonged period.

By its sensibility, its elasticity, so to say, the locomotive is essentially suited for *spurts*. The excess of power which it can develop at need, depends mainly on the ability of the driver, on his acquaintance with the line, and on the resources of his engine. On a line with varying section, his attention should be given not only to *actual* conditions, but to those which are about to follow. The firing, the feeding should be appropriately done, so as to prepare the engine for the work it is about to do. In order to get ready, for example, for taking a steep gradient, the driver takes care to replenish his fire-box, and to keep his pressure well up, and his boiler full of water, so as to avoid feeding on the ascent.

But beyond these exceptional cases, in normal running, there are no grounds for not applying the same mode of estimating the work as to fixed motors. Only this estimate presents greater difficulty, or at least greater uncertainty, especially at high speeds.

According to the engineers of the Eastern of France (*) the available work of the driving-wheels, for the different types of those lines running at the maxima speeds suitable to them, is :

	Speed	POWER	
		total	per sq. ft heating-surface
Crampton engines	50 miles an hour	400 h. p.	0.41
— mixed — —	34 —	300 —	0.30
6 wheels coupled do. (4.6 ft)	19 —	300 —	0.22
8 wheels coupled do. (4.3 ft)	16 —	275 —	0.26
—	15 —	400 —	0.20

These figures are those which result from the conditions of service such as it is (or rather such as it was organized, for the work imposed on the engines, loads and speeds, has been recently revised; the discrepances of work per unit of heating-surface are explained, partly at least, by the diversity of types, by the different proportions of the two elements of the heating-surface, by the smallness of the wheels and their coupling which absorb work, and especially, as we have seen (II, 386, 387) by the habit acquired of long date, of requiring a less specific production of steam from engines of low speed. If it is quite natural that with equal evaporation (and it ought to be very nearly so), an engine should produce more work when it runs fast (within limits of course, compatible with its type) than when it runs slow, for the simple reason that it makes more use of expansion, there are no grounds for two engines with identical boilers, but constructed to run at very different normal speeds, giving different quantities of work on the pistons (if not on the driving-axle).

We have had, however, in what precedes, the opportunity of ascertaining by examples, that, when it is wished or better when it must be, low speed engines perfectly attain, for the gross evaporation, per units of heating-surface and of time, the most elevated figures given by high speed engines, and that their work referred to the steam expended, can therefore offer no other inferiority than that resulting, with the ordinary dimensions of cylinders, from a more or less lengthened admission, and on account of a less expansion.

On steep gradients, the force of things causes the power of low speed engines to be less imperfectly utilized, by pushing the evaporation actively

(*) *De la résistance des trains*, p. 60.

on. It is also in this case, that the measure of the work, absorbed in that case to a great extent by gravity, presents, as has already been said, the least uncertainty.

We have cited the engines with 6 wheels coupled of the Upper Italy lines, developing on the gradients of one in 33 on Mount Cenis at the velocity of 9.3 miles an hour, 273 horse power, or 0.25 h. p. per foot, a lower figure, it is true, to that indicated by the Eastern of France engineers; but we have also seen (II, 415) that the same engines can furnish a more considerable amount of work, 503 h. p. or 0.47 h. p. per foot, which ought not, it is true, to be regarded as quite normal. It resulted not only from the activity given to the evaporation, but also from the speed, and consequently, of a greater amount of expansion.

At the Brenner (II, 412), the engines with 8 wheels coupled give, on the gradients of one in 40, and at a speed of 9.4 miles an hour, an available amount of work of 425 h. p. or 0.40 per foot. That of the eight wheels coupled engines of the Liège incline, is estimated at 400 h. p. or 0.37 per foot. But the difference is explained by the more favourable proportions of the heating-surface of the Belgian type, which has relatively short tubes (12.9 feet), and a very large grate-surface (42.50 square feet).

In general, the relative lowness of the work obtained does not appear to arise, in the eight wheels coupled engines, from the same case as in ordinary goods-engines, that is to say with six wheels coupled. From the first, specially devoted to working steep gradients, about as much is expected as they can do.

If they give no more, it is on the one hand, on account of the smallness of the wheels and the influence of the coupling; on the other and chiefly because their boilers are badly proportioned. The considerable figure of the heating-surface is a delusion. The tubes are generally too long, the fire-box and grate too small. The tank-engines of the Great Central Belgian deserve to be quoted as an example of better proportions. The tubes, 224 in number, are only 11.5 feet long with 1.85 inches internal diameter; the heating-surface is :

Fire-box	90	square feet
Tubes	1259	—
	1349	

In the United States, where the boilers are made of thin, and consequently light plates, the tubes ordinarily short, few in number and therefore the heating-surface comparatively low, but very efficient, the available

work, referred to the unit of heating-surface, is more considerable than in our engines of average speed. It attains and often exceeds 0.37 h. p. per foot. The ratio of the surface of the tubes to the fire-box surface does not seem to exceed 9; that is very nearly the figure to be found in many engines of recent construction. It would be well if this example were followed in Europe (17 and following).

329. M. Fink(*) divides, from the point of view of specific weight, the locomotives employed in Austria, into two classes, according to the conditions of the establishment of the boiler alone :

A. — *Very favourable conditions.*

Absolute pressure : 10 atmospheres at least.

Ratio of the grate to the heating-surface : $\frac{9}{70}$ th to $\frac{1}{80}$ th at least.

Effective work : 0.21 h. p. per square foot.

B. — *Ordinary conditions.*

Absolute pressure : 8 atmospheres.

Ratio of the grate to the heating-surface : $\frac{1}{90}$ lbs to $\frac{1}{100}$ th.

Effective work : 0.16 h. p. per square foot.

Or on the average, 0.19, a low figure, which perhaps arises from the fuel, the indifferent nature of which influences not only its consumption, but also the absolute work.

It is altogether, between 0.19 and 0.37 h. p., according to its type, according to the proportions of the heating-surface, according as the wheels are large or small, single or coupled, that the effective work of a locomotive referred to the square foot of heating-surface will be found to vary. An engine of 1076 sq. feet has thus, in fact, a power of from 200 to 400 horses. Such an engine weighs, full, at the most 50 tons with its tender; we see thus in what proportions the power of an engine weighing 50 tons, exceeds 100 horses (II, 220).

330. *Allowances of fuel.* Among the documents for which we are indebted to the courtesy of the engineers of the companies, there is one which would seem, at first sight, calculated to furnish useful particulars of the effective work of the various types of engine. This is the figure of the mileage allowance of fuel admitted by each of them. But it is easily per-

(*) *Zeitschrift des österreichischen Ingenieurvereins*, for 1870.

ceived that this figure is the result of elements too complex to have by itself, any precise meaning, or to be adapted, without entering into lengthened details, for conclusive comparison. Not only the power of the engine, but also the speed, the ground plan and section of the line, the nature of the fuel, influence it in different degrees; it is only when we become perfectly acquainted with the conditions of work to which it is applied, that it can have a meaning.

On the Northern of France, for example, the allowance for the *Crampton* engines, drawing 12 carriages and under, is, in winter, 33.52 lbs; in summer 31.7 lbs, of a mixture of 90 per cent of large, and 10 per cent of all sorts.

Admitting 30.9 lbs as the real consumption, at the speed of 43.5 miles an hour, and 400 h. p. (328) as the effective work, we have :

Expenditure per hour	$43.5 \times 30.9 = 1344$ lbs
and per hour and horse power	$\frac{1.344}{400} = 388$.

We shall therefore confine ourselves, without multiplying calculations of this sort, to reproducing by way of examples, the new table of allowances adopted by two companies, those of the Eastern and Western of France.

Farther on will be found (Supplement, book VIII, chap. II) the new rules relative to the load of the trains.

WESTERN OF FRANCE RAILWAYS

LOCOMOTIVE DEPARTMENT.

Allowances of fuel as bases for the regulation of the premiums to drivers and firemen.

GREAT LINES.		ALLOWANCES OF FUEL PER TRAIN-MILE.							
		PASSENGER TRAINS.			ORDINARY.		GOODS.		
		Engine with 3 carriages.	Engine with 5 carriages.	Every carriage in addition.	Engine and 30 tons.	Every ton in addition.	Engine and 50 tons.	Engine and 75 tons.	Each ton in addition.
		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Category A. Engines with free wheels.	Winter.	14.11	»	1.69	»	»	»	»	»
	Summer.	12.34	»	1.69	»	»	»	»	»
Category A. Engines with coupled wheels.	Winter.	»	19.40	1.06	17.64	0.14	»	26.46	0.12
	Summer.	»	17.64	1.06	15.70	0.12	»	23.69	0.11
Category B. Engines with free wheels.	Winter.	15.70	»	1.69	»	»	»	»	»
	Summer.	14.11	»	1.69	»	»	»	»	»
Category B. Engines with coupled wheels.	Winter.	»	20.28	1.76	19.40	0.14	»	26.46	0.13
	Summer.	»	17.64	1.57	16.76	0.12	»	24.69	0.12
Category C. Engines with free wheels.	Winter.	15.87	»	1.69	»	»	»	»	»
	Summer.	14.11	»	1.69	»	»	»	»	»
Category C. Engines with coupled wheels.	Winter.	»	21 16	1.76	20.28	0.16	27.34	»	»
	Summer.	»	18.52	1.57	17.64	0.14	24.69	»	»
SUBURBS (Coupled engines).									
Pecq to St. Germain.....	Winter.	»	77.60	3.52	»	»	33.51	»	0.18
	Summer.	»	70.55	3.52	»	»	31.75	»	0.18
Ceinture (Right and left banks)	Winter.	»	28.22	1 41	»	»	33.51	»	0.18
	Summer.	»	24.69	1.41	»	»	31.78	»	0.18
Paris to le Pecq.....	Winter.	»	26.46	1.23	»	»	33.51	»	0.18
	Summer.	»	22.93	1.23	»	»	31.75	»	0.18
Circular.....	Winter.	»	26.46	1.06	»	»	33.51	»	0.18
	Summer.	»	22.93	1.06	»	»	31.75	»	0.18
Versailles (Right and left banks). Auteuil.....	Winter.	»	26.46	1.41	»	»	33.51	»	0.18
	Summer.	»	25.93	1.41	»	»	31.75	»	0.18

VARIOUS ALLOWANCES. (All seasons.)

Lighting.....	165 lbs. per engine, passenger and mixed of every series.
	220 lbs. per goods-engine.
Standing.....	44 lbs. per hour beyond 3 hours.
Shunting and station work...	132 lbs. per hour for engines 1 to 36.
	110 lbs. for other engines of all series.
Time made up.	22 lbs. per minute for express fast, mail and suburban.
	11 lbs. per minute for ordinary mixed and goods.

Classification of the sections in categories.

CATEGORY A.

Paris to Rouen. | Rouen to Elbeuf.

CATEGORY B.

Paris to Rennes.
Rennes to Redon.
Rennes to St. Malo.
Le Mans to Angers.
Le Mans to Caen.
Rouen to Havre.
Rouen to Dieppe and Buchy.
Rouen to Elbeuf and Serquigny.
Laigle to Serquigny.

CATEGORY C.

Paris to Argentan.
Rennes to Brest.
Laval to Caen.
St. Brieuc to Pontivy.
Mantes to Caen and Trouville.
Caen to Cherbourg.
Paris to Dieppe (by Pontoise).
Argentan to Granville.
Pont-l'Evêque to Honfleur.

NOTE. — On account of the running arranged between the drivers, each of them is called on to drive trains the allowance for which may happen to be a little more advantageous, and others for which it may be a little less so.

EASTERN OF FRANCE RAILWAYS.

Locomotive Department.

SERVICE ORDER N° 126

RESPECTING PREMIUMS FOR ECONOMY OF FUEL.

From 1st of April 1876 the allowances of fuel will be thus regulated :

	DEPOTS.	A. — DESIGNATION OF ENGINE. Crampton: Coke, coal and blocks.	Single: Coal and blocks.	Mixed: 1 to 78. Coal and blocks.	Mixed: Ordinary. Coal and blocks.	Goods: Ordinary 0,15 to 0,241. Coal and blocks.	Goods: Creuzot 0,250 to 0,450. Coal and blocks.	Engerth: Coal and blocks.	OBSERVATIONS.
		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
1st section.	Paris	29.98	»	»	35.27	»	58.21	»	
	Epernay	»	»	»	35.27	»	59.97	»	
	Châlons	»	»	»	»	42.33	»	»	(Trains from Coolus : 33.27 lbs).
	Bar-le-Duc	»	»	»	»	(1)38.80	»	»	(1) 49.38 lbs for trains type 30 and below.
	Verdun	»	»	»	29.28	»	51.14	»	
	Sézanne	»	»	35.27	»	»	»	»	
2nd sect.	Flamboin	29.98	»	»	38.80	(2)38.80	»	»	(2) 49.38 lbs for trains type 30 and below.
	Troyes	»	»	»	34.17	56.44	»	»	
	Chaumont-Blesme.	»	29.98	»	32.63	52 91	»	»	
	Gray	»	»	29.98	»	56.54	»	»	
3rd sect.	Nancy	29.98	»	»	33.51	53.79	58.21	100.53	Suburban service exclusively.
	Cirey	»	»	»	36.16	»	»	»	
	Epinal	»	»	33.51	»	39.68	»	»	
	Vesoul-Belfort	»	»	»	31.75	52.91	»	»	
	Lérouville	»	»	»	»	54.67	»	»	
4th sect.	Reims-Amagne	29.98	»	»	32.63	49.38	»	»	
	Mohon	»	»	»	32.63	»	57.22	»	
	Givet	»	»	32.63	»	»	56.44	70.55	
							51.14	»	

B. — MIXED ENGINES DOING THE TRAINS, TYPE 30 AND BELOW.

»	»	»	49.38	»	»	»

C. — ENGINES WORKING DOUBLE.

22 lbs less than the allowance for trains.

D. — UNATTACHED ENGINES, OR NOT COUPLED ON AS AUXILIARIES.

19.40	19.40	21.16	21.16	24.69	28.22	31 75

E. — ENGINES PER HOUR, SHUNTING (3.72 miles).

110.0	111.0	132.3	154.3	198.4	198.4	220.5

F. — ENGINES PER HOUR, STANDING.

26.5	26.5	33.1	44.1	44.1	44.1	55.1

G. — SPECIAL ENGINES FOR STATION WORK.

La Villette and Gray.	Per hour of working	Coke 176 lbs,	coal 187 lbs.
	do. of standing	do. 33 »	do. 44 »
In the other depôts..	do. of working	do. 143 »	do. 154 »
	do. of standing	do. 33 »	do. 44 »

The allowances brought into the preceding table, for mixed engines, are applicable :

1st. — A. To the train types 35 and above.
2nd — B. — 30 —

A supplementary allowance of 1.76 lbs per vehicle per mile, is made, when the load exceeds the following limits :

1st. *For the train-types* 55.60 *and* 65, *worked by single engines* :

10 vehicles on the line from *Paris* to *Avricourt*,
8 do. do. *Paris* to *Belfort*.

2nd. *For the train-types* 45 *and* 50, *drawn by single engines* :

14	vehicles on sections	A and B	10	vehicles on the section	E.
12	do.	C,	8	do.	F,
11	do.	D,	7	do.	G.

3rd. — *For the train-types* 45 *and above, drawn by single engines* :

20	vehicles on sections	A and B,	12	vehicles on the sections	F,
18	do.	B	10	do.	G,
16	do.	D	7	do.	H.
14	do.	E			

The drivers of passenger-trains, can only have the benefit of the supplementary allowance for extra-load, by having recorded on their way-bill the composition of the train from such to such station, by the conductor of the train (every statement of the load not certified by the conductor, will be considered as nothing).

For the train-types 40 *and below*, the supplementary allowance per mile and per unit of extra-load over and above the minimum of the table of the load of the trains, is fixed at :

1.76	lbs on the sections	A and B,	5.64	lbs on the sections	G, H and I,
2.32	do.	C and D,	7.05	do.	K and L.
3.22	do.	E and F,			

331. Let us quote still another figure, taken from the Orleans lines : During the working of 1875, the consumption of the locomotives was 276 000 tons for a train-mileage of 15 540 000, and for an engine mileage of 17 240 000, which gives 41.9 lbs per train-mile, and 35.22 lbs per engine-mile.

CHAPTER II.

RESISTANCES AND USEFUL EFFECT OF THE LOCOMOTIVE.

332. The useful effect of a steam-engine may be regarded in different ways, according as the whole machine is taken into consideration, or only one of its elements : that which receives and distributes the work, abstraction made of that which produces and stores up the heat whence this work is derived.

The work available on the driving-shaft may be referred either to the work acquired by the pistons, or to the utilizable work accumulated in the shape of heat in the boiler, or to the equivalent of the total heat disengaged by the fuel.

The first ratio only expresses the useful effect of the machinery proper. It leaves on one side the more or less satisfactory conditions of the production and use of the steam, while in the second, these are comprised.

The ultimate object being to extract from the unit of weight of a given fuel, the greatest amount of work on the shaft, it is the third ratio which would alone give an idea of the value of the machine as a whole. But if the useful effect is indifferent, we cannot tell whether it is the fuel which is badly utilized in the production of the work on pistons, or indeed if the passive resistances absorb too great a portion of the work in its transmission from the pistons to the driving-shaft.

Alone, no one of these ratios is sufficient. The determination of the first should always be completed by that of the fuel consumed, and as much as possible, which is less easy, by that of the effective work to the fuel consumed, is the most significative; for the engine itself, it is the weight of steam expended for a given amount of work.

It is at the same time clear, that the available work referred either to the fuel of a given nature, or to the steam produced, only characterizes the en-

gine by taking its principle into account. Between one motor which, by its construction, makes little use of expansion, and another which does so largely; between a condensing-engine and another, like the locomotive, for which condensation is forbidden, the comparison could not be legitimate, and the motor which gives the least work per unit of fuel given, or per unit of steam expended, may be in reality the most perfect.

In reality, it is generally considered sufficient, to determine the ratio between the quantities of work on the driving-shaft, and on the pistons. This is what is understood by the *useful effect*, without any other designation. It is the *useful effect of the machinery only*.

Let us then consider its measure.

A locomotive drawing a given train on a uniform section and with a uniform speed, the resistance of the train drawn is given either by calculation, or better by the dynamometer. The sum of the mean effort of traction, resistance of the air acting directly on the engine, and the resistance of the latter *as a vehicle*, a sum multiplied by the speed, expresses the work θ obtained in the unit of time on the driving-wheels.

The resistance of the engine as a vehicle is easy to determine directly, for example by drawing it through the medium of a dynamometer, after having taken off the connecting-rods, and if necessary, the coupling-rods. This special resistance may, at the same time, often be assimilated to that of the carrying-stock.

The coupling, especially if it extends to 6 or 8 wheels, introduces an element of resistance into the engine which depends essentially on the state in which the machine is kept; nothing, if the fitting is perfect and the diameters of all the tires rigorously equal, this resistance becomes very appreciable if these conditions are not fulfilled, and if the inequality in the wear of the tires gives rise to sliding on the rail. This resistance should moreover, be put down to the account, of the parts of the machinery, and not to that of the vehicle. The coupling-rods belong to the mechanism of transmission, and the work available definitively on the driving-wheels, is reduced by that which is absorbed by the resistances due to the coupling, as well as by that absorbed by the parts of the moving machinery proper.

The effective work Θ, applied by the steam to the pistons, can only be estimated with sufficient exactness by means of *Watt's* indicator, or rather by means of the improved apparatus founded on the same principle.

The ratio $\frac{\theta}{\Theta}$ expresses the *useful effect* in the restricted sense pointed out farther back, that is to say the useful effect of the machinery; and the *resis-*

tance of the organs, including, if necessary, those of the coupling, is expressed by $\frac{\Theta - \theta}{V}$ lbs, V being the velocity in feet per second.

§ 1st. — Resistance of the engine as vehicle.

333. The assimilation of the engine to the waggons for the *resistance of the vehicle*, is only admissible for locomotives with rather large wheels; in low speed engines, the ratio of the radii of the journals and wheels is much more unfavourable, and at the same time, the effort of traction t, increased in the inverse ratio of the velocity, augments in a notable proportion the pressure $\sqrt{P^2 + t^2}$ of the axles on the bearings. We have seen (II, 397) that the resistance, as a vehicle, of a *Kœchlin* tank engine, was estimated at 22 lbs a ton. This value, so superior to the resistance of waggons, includes according to its method of determination, the resistance of the air acting on the engine; but at the speed of 10.5 miles an hour, and the air at rest, that element may be very nearly neglected. There might also have been curves on the line, the influence of which on a vehicle with a wheel-base of 13 feet was appreciable. But with its inside journals of 6.7 inches in diameter, and its wheels of 3.94 feet, the ratio $\frac{r}{R}$, which in the waggons does not exceed 0.085, rose in the engine as high as 0.14, which was quite sufficient to explain a notable enhancement.

Other observations would lead to much higher figures; according to numerous dynamometrical experiments made by the locomotive department of the Eastern of France, between *Luxembourg* and *Pepinster*, an engine with eight wheels coupled (II, 259) weighing 60 tons, including the tender, at the absolute pressure of 9.5 atmospheres, would draw in an hour 180 tons up one in 40, and getting up 1,148 feet in a distance of 8.70 miles.

" The work effected would be : 410 h. p., 277 of which were absorbed by the train, and 133 by the engine (*). "

Admitting these bases, the work absorbed by the engine itself, during the hour's journey, would be $133 \times 550 \times 3.600 = 151\,893\,000$ foot pounds; there

(*) By a mistake in the printing this figure was given at 26.5 lbs.
Report of MM. *Gerhardt* and *Flaman* on the *Lans-le-Bourg* inclined plane; autography 1875.

remains, for the work of the resistance of the vehicle, 107 842 100 foot pounds and for this resistance itself,

$$\frac{107.842.100}{45.936} = 2.348 \text{ lbs, or, per ton, } \frac{2348}{6,0} = 39.13 \text{ lbs.}$$

In the face of so high a figure (all the higher as it applies to the engine and tender taken together), it might be asked if « *work effected* » might not mean the work on the pistons and not on the *driving-wheels*, in which case, the 39.13 lbs would include the resistance of the machinery. But that value would then be, on the contrary, too low, as we shall see farther on (343).

The roundabout methods, moreover, merit little confidence.

334. *Direct measure.* The following are the results obtained by MM. *Vuillemin* and his collaborators (*), following the method pointed out just now (332), which leaves only the resistance to estimate.

1st. **Resistance of the vehicle** (all the side-rods taken down).

ENGINES WITHOUT TENDER.	SPEED.	RESISTANCE PER TON.
	miles an hour.	lbs.
Mixed engines with 4 wheels coupled (5.28 feet diameter).	17.4	10.12
	17.4	12.54
	28.0	14.74
Engines with 6 wheels coupled (4.27 feet)	16.8	14.22
	15.0	13.35
Engines with 8 wheels coupled	3.7 to 16.2	24.64

2nd. **Total resistance of the vehicle and the coupling of the wheels** (connecting-rods taken down, side-rods in place).

Same type of mixed engine	16.1	9.68
	23.6	10.08
	16.1	12.77
	22.4	13.64
Same type of 6 wheels coupled engine	16.8	14.47
	16.8	14.92

(*) *De la résistance des trains*, pages 34 and 35.

The influence of the coupling would thus be very slight, even for six wheels : which the authors attribute to the circumstance, « that the experiment was made on a straight line » ; but the coupling cannot cause any notable resistance, excepting on account of the inequality of the diameters of the wheels, and that cause would act on a straight line as well as on a curve.

The tires were doubtless new, or fresh turned, and consequently, the diameters quite equal. The resistance due to coupling may, no doubt, be very slight, nothing even : but it is not the less doubtful that it may reach a considerable amount. It is a question of maintenance.

§ II. — Resistance of the organs.

335. *Remarks on the elements of this resistance.* — The work acquired by the pistons only comes to the driving-wheels impoverished by losses, always considerable, and all arising from the frictions. The mutual pressures between the rubbing parts are known, or can be estimated with a certain degree of approximation ; the distances gone through are known ; the resisting works could thus be calculated, if we were not stopped by the uncertainty which reigns as to the values to be attributed to the coefficients of these frictions, which are very variable. Thus it has hardly ever been attempted to proceed by the individual estimate of the resistances ; it is in a lump that they are measured.

One remark before going into the matter. In an engine in a good state of repair (this is almost always the case with locomotives), the wear, that is to say the immediate destruction of the work of friction by a molecular work, is extremely slight; almost all the work of the friction is transformed into heat. The latter may, as has already been said, react on the magnitude of the coefficients, but it is not *entirely lost* for the production of utilizable work. The heat disengaged by the friction of a bearing, of a piston cross-head, etc., is of course definitively lost; but it is not so as regards that produced by the friction of the piston against the sides of the cylinder, of a slide-valve on its seat. Contributing to prevent the cooling of the cylinder, that heat assists the effect of the steam.

The friction of the pistons, and that of the slides, are the two principal resistances. The first, independent of the pressure of the steam (unless when the latter presses the segments) (193), might theoretically be nil, seeing

that the simple contact with the cylindrical side would be sufficient to render the piston tight; but experience proves that a notable pressure is indispensable in order to avoid leaks, and if the slightest griping occurs, the resistance becomes very great.

The slides are even more subject to gripe than the pistons. The fear of this effect has a great deal to do with the repugnance « still felt by some engineers, to raising the pressure in locomotives (*). »

In actual engines of average power, the work of the slides absorbs from 30 to 35 horse power, admitting $f = 0.3$.

Some persons think that the effective pressure to which the slides are subjected is taken at too high an estimate. Mr. *J. Adams* seems to have ascertained that there is always between the face of the slide, and its seat, a film of steam uncondensed, possessing the whole of its elastic force (**). But admitting that at times it may be so, it seems difficult that a leak should not in that case be imminent.

Many of the resistances coming into play are only of very secondary importance, on account of the slightness of the pressures, or of the distances gone through, or both. Such are the frictions of the ends of the connecting-rods, and of the side-rods on their pins, of the eccentric clips on their sheaves, etc. But the total resistance may be notably affected by slight alterations, resulting from the service of the engine. We have already cited the inequality of the diameters of coupled wheels. The tightening of the wedges of the grease-boxes in their guides, when it takes up unequal wears, disturbs the distance between centres, and the parallelism of the axles, and reacts not only on the resistances, but on the running of the engine.

336. Let us consider, as we have already done, two engines identical as regards boiler, as regards machinery, differing only by the diameter of the wheels and the adhesion, and working with the same number of revolutions, at the same pressure, and with the same amount of admission. The resistance of the *vehicle* will naturally be greater for the engine with the small wheels; as to the work of the resistance of the organs in the unit of time, or per revolution, it is evidently the same in the two cases, and consequently this resistance itself, the quotient of the work by the speed, is less for the engine with large wheels.

(*) These organs work, it is true, in certain machines worked by a column of water under far more considerable pressure, but under conditions which have absolutely nothing in common with those of the distributing-slides in steam-engines.

(**) *Handbuch*, Vol. III, pages 473 and 553, article by M. *Petzholdt*.

The two engines having very nearly the same weight, the resistance of the organs per ton, will be very nearly in the inverse ratio of the diameters of the driving-wheels, or of the velocities.

337. It is clear that the work of the resistance of the organs varies much in a given engine, according to the conditions of the work of the steam. It is a maximum when the admission is maximum, the slides being at their full travel, and the mutual pressures between the parts, their greatest value, excepting for the pistons, the pressure of which against the sides of the cylinders does not vary. It is a minimum when the regulator is closed, the pressures depending in that case only on the regulation of the engine, on the tightening of the keys, bolts, etc.

Let us however remark that when the regulator is closed, the slide ought to be at its maximum travel (148, 3rd), unless the blow-off cocks are open, and unless on the other hand, the absence of steam in the cylinders might determine the griping of the piston. We have dwelt enough on this point not to return to it.

§ III. — **Experiments**.

338. Let us pass on to the experiments made in order to determine : 1st, the minimum resistance of the organs, that is to say that which is developed in a cold engine, or, what comes to the same thing, in an engine running with the regulator closed; 2nd, the resistance, of which the preceding is an element, which is developed in an engine working under the action of steam.

Here first are the results which make part of the fine series of experiments of the three engineers of the Eastern of France, who have, on this point also, varied the mode of observation :

First mode (*). The engine in steam and lighted, followed by its tender, was started at different speeds. These having become uniform, the regulator was closed, and the distance run up to stopping measured; from which the speed and the mean resistance were deduced.

To the tender was attached a waggon, of known resistance, and in which the observer was placed.

(*) *De la resistance*, p. 7.

A (*). — *Mixed engine with its tender.*

MEAN SPEED	RESISTANCE PER TON on a level of the engine and tender.
Miles an hour	lbs
6.8	7.17
9.3	8.96
12.4	9.74
14.3	12.77
B. — *Six wheels coupled engine* (0.123) *and its tender.*	
5.6	11.92
7.5	14.40
10.0	16.84

Compared to those which refer to the vehicle alone (334), these figures which include also the constant part of the resistance of the machinery, seem low; but they apply to the engine and tender taken together, and the latter which has no machinery, lowers the mean.

Second method. The dynamometer-waggon was placed in between two engines, one of which drew the other which had the regulator closed, and the valve-motion at the minimum travel, but the blow-off cocks open in order to reduce the compression of the air; at each stroke, a stop allowed the pistons of the engine drawn to be lubricated during the trip.

ENGINES.	SPEED.	MEAN RESISTANCE PER TON of the engine and tender.
	miles an hour.	lbs
Engine single (type 1).....	28	12.27
Mixed engine (type 14).....	28	14.36
Engine 6 wheels coupled (type 15)....	26	22.94 (4.27 feet wheels).
Engine 6 wheels coupled (type 20)....	15	21.32 (4.59 feet wheels).

These figures are notably higher than the preceding ones; this is partly the effect of the higher speeds, but the mode of observation in itself tended to enhance the resistance on account of the somewhat long distance (some miles) run by the machine drawn, with its cylinders dry, without steam and without oil, while in the preceding series, it ran only a few hundred yards after the closing of the regulator.

It was also ascertained that the single engines and those with coupled wheels, only

move by themselves, when the gradient reaches one in 200 or one in 166. For engines with six wheels coupled an inclination is required of one in 111 or one in 100.

This accords pretty well with a trial made on the line from *Paderborn* to *Attenbecker*. An engine with six wheels coupled, cold, required, down one in 100 the frequent intervention of its tender-brake, in order to check its speed. The resistance of the vehicle and of the machinery (coupling included) was thus inferior to 22.4 lbs per ton.

339. The engines which served, after having the connecting and side-rods taken down, for the determination of the resistance as a vehicle, were equally drawn in steam, and all fitted, through the medium of the dynamometer; they gave the following results (*).

ENGINES.	SPEED.	RESISTANCE PER TON of the engine *alone*.
	miles an hour.	lbs.
Mixed engine with four coupled wheels 5,51 ft (type 14)	16.8	21.46
	27.3	24.82
	18.6	21.57
	28.0	26.43
Engine with 6 wheels coupled 4,27 feet diam. (type 15)	16.8	27.78
	18.0	26.88

These figures exceed, in their turn, those of the preceding tables referring to the same types; that is explained by somewhat higher speeds, and by the absence of the tender.

Engines with 8 *wheels coupled* (0.177 and 0.168) *with their tenders.*

The first weighing with its tender 63.10 tons, was under steam, and was drawn, the regulator being closed; the second, weighing 64.7 tons was drawn cold.

0,177 { 1st trial. 1.46 tons / 2nd do. 1.47 tons — 0,168 { 1st trial. 1.36 tons. / 2nd do. 1.37 do.

The engine cold, although the heaviest, has thus a resistance less than the engine in steam, which can only be an anomaly without any relation to this difference of state.

The mean of the four trials gives 48.16 lbs per ton, tender included.

For the engine alone, the figure would be higher still. The engine weighs

(*) *De la résistance*, etc., table of page 35.

46 tons. Admitting for the tender 16 tons and a resistance of 11.2 lbs, we have for the resistance of the whole $(46 + 16) \times 47.4 = 2{,}939$ lbs; resistance of the tender, $16 \times 11 = 176$ lbs; resistance of the engine alone 2,763 lbs, or $\frac{2{,}763}{46} = 60$ lbs per ton. The small diameter of the wheels (4.13 feet) no doubt contributes to the greatness of the resistance, but it is possible that the coupling of the four wheels has a great deal to do with it.

M. *Lechatelier* has given, for the resistance of engines with eight wheels coupled, drawn with the regulator closed, figures greatly inferior to the preceding ones, which is the less explainable, as precisely the same engines are referred to, and experiments made by the same engineers.

" When an engine " says he (*), " for example a goods-engine with eight wheels coupled is drawn, the regulator closed by another engine, the resistance which it opposes to movement becomes raised *by the friction of its machinery and of its coupling-rods*, to 18 or 22 lbs per ton, tender included. The experiments of MM. *Vuillemin*, *Guébhard* and *Dieudonné* give, at velocities of from 10 to 11 miles an hour, a resistance of about 22 lbs per ton. An experiment at which I was present, on the *Orleans* line gave 18.6 lbs per ton for an engine with eight wheels coupled at a speed of 16.8 miles an hour. We may thus reckon, under ordinary circumstances, at speeds of from 15.5 to 18.6 miles an hour, on an approximate average of 20.16 lbs for an engine with eight wheels coupled and its tender weighing together 62 tons. "

There is no possible confusion : it is certainly the *total* resistance which the engine drawn opposes to its movement that is meant. Now, it is neither 20.16 nor 22 lbs, that the experiments of the three Eastern of France engineers gave, but 48.16 lbs a ton.

In order to get the resistance per ton, of the engine alone, M. *Lechatelier* deducts the weight of the tender, 16 tons, attributing thereto a resistance proper of 7.84 lbs; but that figure is far too low (341).

The same error is reproduced in the same paper (**), in which the resistance of an engine with eight wheels coupled (vehicle and constant portion of the resistance of the machinery) is taken equal to 22.4 lbs per ton.

It may thus be concluded from these figures, that, when the speed is at its ordinary rate, and when the engine is drawing its normal load, which brings the full extent of the resistance of the organs into play, the resistance per ton of the type with eight wheels coupled, attains very considerable values.

(*) *Mémoire sur la contre-vapeur*, 1869, p. 40.

(**) *Ditto*, p. 105.

340. The preceding series was recommenced on the same engines, with speeds somewhat different, after the side-rods only were taken down. Thus was obtained (*):

ENGINES.	SPEED.	RESISTANCE PER TON of the engine *alone*.
	miles per hour.	lbs
Mixed engines (type 14).....	19.9	19.46
	27.3	23.76
	18.6	32.70 { Engine cooled, lubrication imperfect.
Engines with six wheels coupled (type 15).	9.9	30.46
	10.6	24.19

Here again, there is nothing tangible as to the influence of the coupling.

At the same time, trials so few in number would hardly be free from the action of purely accidental causes, especially if it be borne in mind that two engines of each type were dealt, and not one alone; which had the advantage of representing the effective mean somewhat better, but also, from the point of view of comparisons, the disadvantage of introducing the influence of inevitable individual differences.

341. *Resistance of the tender alone* (**) (dynamometer, four-wheeled tender).

SPEED	RESISTANCE PER TON
—	—
Miles an hour	lbs
10.0	11.35
16.8	11.15
19.9	12.16
26.3	14.69
28.0	16.68

342. *Minimum resistance of the organs.* Knowing approximatively for some types of engines : 1st, their resistance as vehicles, 2nd, their total resistance when they run with the regulator closed, the difference represents the constant portion of the resistance of the organs or the minimum of that resistance, on condition of course of only comparing the figures obtained at equal speeds, or very nearly so.

(*) *De la résistance*, table, p. 35

(**) Ditto, p. 15.

We have thus :

ENGINES.	SPEED.	RESISTANCE PER TON OF THE ENGINE ALONE.		
		Vehicle.	Total, regulator closed.	Organs (constant portion).
	miles an hour.	lbs	lbs	lbs
Mixed engines (type 14)..	16.7 to 17.4	10.12	21.46	11.34
do. do.	28	14.74	26.43	11.69
Engine 6 wheels coupled type 15.....	16.7	14.22	27.77	13.55
Engine with 8 wheels coupled..	3.7 to 6.2	24.64	48.16 including tender. 56.00 tender deducted.	31.30

343. *Additional resistance of the organs, due to the work of the steam.* The complete resistance of the organs of an engine in work is the effort corresponding to the excess of motor-work acquired by the pistons over that which is *available* at the driving-wheels.

The most certain means, if not the most simple, of obtaining the first is the quadrature of the diagrams taken off by means of the indicator. The second is obtained either by calculating the resistance of the gross train (vehicle of the engine included), or by adding the resistance of that vehicle to that given by a dynamometer let in between the engine and the train.

In order to avoid the use of the indicator, the Eastern of France experimentalists endeavoured to make up for it by calculating, for each notch of admission, the effective work applied by the steam to the pistons. The initial and first pressures being generally unknown, they experimented at a speed low enough for the pressure *to be supposed equal*, during the admission, to that of the boiler, and the back-pressure during the exhaust, to that of the atmosphere (which is almost always very closely exact). The work of the expansion was deduced thence approximatively by *Mariotte's* law, as was also that of the compression.

The following example is taken from the paper quoted (*).

(*) *De la résistance*, etc., p. 807.

Engine with 6 wheels coupled (type 20), wheels 4.27 feet. Absolute pressure 8.25 atmospheres.

Train drawn up one in 167, at the speed of 9.3 miles (13.64 feet per second).

Work of the steam on the piston, at the 6th notch, per second : 122.961 foot pounds.

114,073 ft. pds Work on the driving-wheels.	1st. Resistance of the train drawn, dynamometer	ft lbs 94,934	Work on the driving-axle.
	2nd. Resistance of the engine and tender as *vehicle*, 53 tons at 13.23 lbs on a level, 53 tons × (13.23 + 13.23) × 13.64 = ...	19,134	

Work absorbed by the organs 122.961 — 114.073 = 6.888 foot pounds.

Corresponding effect at the speed of the engine $\frac{8.888}{13.64} = 650$ lbs,

and per ton of the engine, weighing 33 tons = 19.84 lbs.

The constant portion (independent of the pressure of the steam) being, for type 15, analogous to the latter, very nearly 13.23 lbs per ton, there remains for the additional portion, 6.61 lbs per ton.

The total resistance on a level of the engine, in the circumstances in which it was act ing, was then decomposed in this way :

Vehicle	13.23	do.
Organs { Constant portion	13.23	lbs per ton.
Organs { Variable do	6.61	do.

Useful effect of the machinery. The effective work of the steam on the pistons being 122,961 foot pounds per second, the available effect on the driving-shaft 114,073 foot pounds, the useful effect of the machinery is $\frac{114,073}{122,961} = 0.92$, a figure the high amount of which is explained by the lowness of the speed, which reduced the resistances.

The additional resistance was not determined for mixed and single engines; they run, in effect, at speeds which do not permit of supposing, as for the preceding ones, the pressure of the steam during admission, constant and equal to that of the boiler. The authors thus contented themselves with admitting that that element has the same value in the three categories, whch gives for the total resistance of the two last :

	MIXED.	SINGLE.
	lbs per ton.	lbs per ton.
Vehicle	11.70	6.72
Organs { constant portion	9.59	4.48
Organs { variable do	6.72	6.72
	28.01	17.92

The authors conclude, altogether, that at the normal service speeds, the total resistance per ton of the engines, including the tender, is expressed by the following figures :

Crampton	17.92
4 wheels coupled	23.52
6 do.	28.00
8 do.	44.80

It is natural to associate the tender with the motor, of which it forms an integral part; but this element lowering the mean resistance, it is of consequence to know in each case if the figures indicated apply to the whole thing, or to the engine alone.

344. *Other experiments.* Experiments by the simultaneous use of the indicator and dynamometer have been made on several occasions in England, and in France on the *Orleans* lines. M. *Forquenot* thus found, for engines with eight wheels coupled, total resistances of 49.28, 51.52 lbs, and beyond.

We have seen (225) that the resistance of the vehicle and of the organs of a four-wheeled engine in counter-steam, drawn by another, has been estimated at a mean effective pressure of 17.07 lbs on the square inch of the pistons; the latter having a diameter of 16 inches, 22 inch. stroke, and the diameter of the driving-wheels 5 feet, this pressure represents a resistance of 1,651 lbs; but the weight of the engine not being indicated, the figure per ton cannot be given.

M. de Pambour's formula. The additional resistance of the organs was the object of several experiments on the part of M. *de Pambour* (*).

Although by comparing the values obtained for the efforts of traction exerted by the engine, he found numbers varying almost from simple to double, he believed that he could admit the proportionality of these two forces, so that the total resistance of the organs would be of the form $C + k\frac{\theta}{V}$, C being the constant part, θ the work available on the driving-shaft, and V the velocity. The values which he proposed for k are : 0,137 for single engines, and 0,215 for coupled engines.

M. Gooch admitted this law also, making $k = 0.15$.

In the application of the coefficient such as it is indicated by M. *de Pambour*, there is a detail to rectify :

" Relatively to the number in which the additional friction of engines ought to be calculated, " he says (**), " we should bear in mind that it ought to be reckoned for each

(*) *Traité des locomotives*, 2nd edition, 1840, p. 256.

(**) Ditto p. 263.

pound of total resistance exerted against the movement, that is to say that the resistance produced by the friction of the *waggons* must first be calculated, that of gravity and that of the atmosphere, and that it is on the whole of those taken together, that the friction should be taken at the rate pointed out farther back."

It is evident that, in the order of ideas in which M. *de Pambour* placed himself, there must also be included among these resistances, that of the engine itself as a vehicle. This resistance contributes like all the others to the work of the friction of the organs. It is not only the effort on the coupling-bar that is required to be estimated, but, as we have said, the effort measured on the driving-wheels, or $\frac{\theta}{V}$. Moreover, the hypothesis of the proportionality of the effort of traction is convenient, natural enough, but nothing more.

M. *Zeuner* (*) admits by preference the proportionality of the resistance in question to the *maximum* theoretical work $\left(\frac{Q(J-J')}{\quad}\right)$ (361), but admitting a single coefficient, much less than those of M. *de Pambour* (**).

The experiments are not numerous enough, and their elements not sufficiently known for it to be possible to establish a relation between the variable portion of the resistance of the organs of an engine, and the conditions of the work which it effects.

It appears, for example, that in the experiments of M. *Forquenot* on eight wheeled coupled engines, and from which were deduced total resistances of 49.28, 51.52 lbs, and beyond, per ton of the engine alone,

"there was little difference, whether the engine worked with a great or small amount of admission (***);"

whence it would seem to result that the additional resistance is, altogether, of little consequence, seeing that its variations, in connection with those of the admission, would little effect the total result; but this point is not well established.

(*) *Théorie mécanique de la chaleur*, p. 499.
(**) *Ditto*, p. 506.
(***) *Lechatelier*, Mémoire sur la contre-vapeur, p. 41.

Experiments made with the indicator and dynamometer on the Great Western.

7 feet gauge. — Passenger-engine with 8 wheels (*Great Britain*), weight, tender included : 50 tons. — Load drawn : 100 tons.

SPEED.	RESISTANCE OF THE ENGINE AND TENDER.			RESISTANCE PER TON OF THE ENGINE AND TENDER		
	Vehicle.	Organs.	Total.	Vehicle.	Organs.	Total.
miles an hour.	lbs	lbs	lbs	lbs	lbs	lbs
13.0	381	234	615	7.75	4.70	12.45
20.0	465	304	769	9.45	6.18	15.63
45.0	725	593	1,318	14.74	12.05	26.79
60.0	999	776	1,775	20.29	15.76	36.05

According to M. *Wellkner* (*), the total resistance (vehicle and organs) in lbs per ton of a six-wheeled engine and its tender is expressed by :

$$t = 13.44 + 0.025231\,V^2, \text{ for single engines,}$$
$$t = 17.92 + 0.025231\,V^2, \text{ for four wheels coupled,}$$
$$t = 26.88 + 0.025231\,V^2, \text{ for six wheels coupled,}$$

V being the velocity in miles per hour.

If V = 13.95, we have respectively 18.37 lbs, 22.85 lbs, 31.80 lbs ; and for the total resistance of an engine of 50 tons tender included : 904, 1124, and 1565 lbs.

The progression of the constant does not represent only the influence of the side-rods, but also that of the diameter, which is less when they are coupled.

The formula was not extended to engines with eight wheels coupled, which are very little employed in the North of Germany.

When it is desired to have approximatively the *total* resistance of a gross train of weight π, that is to say the mean effective effort *on the pistons*, referred to the circumference of the driving-wheels, it is sometimes considered sufficient to increase by 25 per cent, the values given by *Wyndham Harding's* formula (II, 394), which became :

$$R = 7.50 + 0.416\,v + 0.1693\frac{V^2}{\pi},$$

and gives :

(*) *Organ für die Fortschritte etc.*, 1875, p. 76.

v.	R.		
	$\Pi = 100$ tons.	$\Pi = 200$ tons.	$\Pi = 300$ tons.
miles an hour.	lbs	lbs	lbs
18.6	15.90	15.61	15.49
24.9	18.96	18.43	18.14
49.8	25.48	24.30	23.91
56.0	32.55	30.42	29.71
62.0	40.12	36.82	35.72

§ IV. — **Measure of the resistance of the organs and of the useful effect of the machinery by the consumption of the engine; 1st, drawing its train; 2nd, drawing itself alone on the same section, and at the same speed.**

345. The measure of the work Θ on the pistons, and of the work θ on the wheels, requires the use of an indicator and a dynamometer, which are not always available, and the cooperation of somewhat experienced observers. The result may be attained by an indirect means, and correct enough, provided there be no hurry, as is too often with regard to consumption, to deduce figures from experiments too few in number, and continued too short a time.

This mode consists in measuring the fuel consumed by the engine, in two circumstances: 1st, drawing its load, at a uniform speed; 2nd, drawing itself alone, at the same speed, on the same section and under the same atmospheric conditions.

The difference of the two figures represents the consumption due to the train; and we are astonished by the enormous part taken by the engine in the total consumption.

Supposing that trials are carried out on a straight line, and that the engine weighing π tons, tender included, draws at the speed V feet a train of P tons.

Let: C lbs be the consumption of the engine drawing the train P at the speed V, and c that of the engine drawing itself only.

C — c is the consumption per mile due to the train. If it were objected that the engine, when it draws the train, consumes for its own traction more fuel than when it drawing itself alone, seeing that the resistance of its organs is greater, it would be sufficient to remark that the increase of resistance is the effect of the effort of traction of *the train*, and that it must therefore be

placed to the account of the latter. The consumption per ton of the engine is thus $\frac{c}{\pi}$ and the consumption per ton of the train $\frac{C-c}{P}$.

Let: r be the resistance in lbs per ton, of the train drawn at the speed V; ρ the resistance per ton, as *vehicle*, of the engine, at the same speed, O the resistance per ton of the engine, due to the friction of the machinery, the consumption per ton of $\frac{C-c}{P}$ of the train drawn corresponds to the effort r; the consumption $\frac{c}{\pi}$ of the engine, to the effort $\rho + O$.

$$\frac{C-c}{P} : r :: \frac{c}{\pi} : \rho + O;$$

whence $$O = \frac{c P r}{(B-c)\pi} - \rho.$$

We have then: If the type of engine allows ρ to be taken $= r$,

$$O = r\left(\frac{c}{C-c}\frac{P}{\pi} - 1\right). \quad . \quad . \quad . \quad . \quad (a)$$

Duty of the machinery, — The work on the shaft is: $(P+\pi)\,r\,V$.

The work on the pistons: $\left\{(P+\pi)\,r + \pi O\right\} V$,

and the duty $$E = \frac{(P+\pi)\,r}{P r + \pi (O+r)} \quad . \quad . \quad . \quad . \quad (b),$$

(a) gives: $O + r = \frac{c}{C-c}\frac{P}{\pi}$; carrying forward and reducing,

(b) because $$M = \frac{P+\pi}{«}\,\frac{C-c}{c}.$$

If the speed is not very low, a slight correction of the value (a) of O is necessary. This value includes, in effect, an element foreign to the resistance of the organs, which is the portion of the resistance of the air directly against the engine.

The measure of the consumption, with and without load, gave for four types of engines on the *Lyons* Railway, the following results:

SPEED.	COKE CONSUMED PER MILE.			COKE CONSUMED PER MILE AND PER TON.	
	The engine drawing the train.	The engine (and tender) alone.	Of the train drawn.	Of the engine.	Of the train drawn.
Miles an hour. Feet per sec.	lbs	lbs	lbs	lbs	lbs
1st. *Crampton* engine, $\pi = 44.8$ tons, $P = 80.8$ tons.					
37.3 = 54.98	23.87	13.27	10.60	0.29	0.13
2nd. Ordinary passenger, $\pi = 43.76$ tons, $P = 139.3$ tons.					
28.0 = 41.25	29.16	12.34	16.81	0.28	0.12
3rd. Goods-engine with outside cylinders, $\pi = 53.6$ tons, $P = 318$ tons.					
15.5 = 22.97	45.05	21.31	23.73	0.40	0.08
4th. Goods-engine with inside cylinders, $\pi = 44.76$ tons, $P = 294$ tons.					
15.5 = 22.97	42.78	15.71	27.06	0.35	0.09

These experiments were not made with the view of the results which I have just pointed out, that is to say, the determination of the resistance proper of the organs and the amount rendered by the machinery.

There is however a certain interest in deducing these values; but a given quantity is wanting for that, the value to be attributed in each case to the coefficient r. Admitting respectively for the four velocities,

$$r = 20.16 \text{ lbs a ton} \mid 13.44 \text{ lbs a ton} \mid 8.96 \text{ lbs a ton} \mid 8.96 \text{ lbs a ton},$$

we find :

1st engine	$O = 25.20$ lbs	per ton :	work rendered	E. 0.682
2nd do.	$O = 17.92$	do.	do.	. . . . . 0.76
3rd do.	$O = 38.41$	do.	do.	. . . . . 0.59
4th do.	$C = 24.19$	do.	do.	. . . . . 0.72

In order to make the correction relative to the direct action of the air on the engine, there must be subtracted from each of the values of O, by estimating at 43 square feet the surface acted against.

	lbs	lbs		lbs
for the first engine :	$\frac{176.4}{44.8} = 3.75$	remains	$O = 21.05$	
do. second do.	$\frac{99.21}{43.7} = 2.27$	do.	15.43	
do. third do.	$\frac{30.9}{53.6} = 0.57$	do.	37.26	
do. fourth do.	$\frac{30.9}{44.76} = 0.66$	do.	23.24	

The substitution of these values in the expression of the net work, would raise that perceptibly, for the two first engines, on account of the speed.

L'*Appenin* engine (II, 332, 6th) was submitted later to the same experiment. The following are the results :

1st. *Engine loaded.* Journey, *Paris* to *Montereau* and back. 98 miles. Weight of engine 60 tons; weight drawn (mean) 548 tons; mean speed, 15 miles an hour (22 feet a second).

Total consumption : 4.018 tons coal (agglomerate), or 90.1 lbs per mile, lighting included, and 88.14 lbs lighting (333 lbs) deducted.

2nd. *Engine without load.* Total consumption : 1.741 tons or 35.51 lbs per mile, lighting included, and 35.31 lbs lighting deducted.

Admitting again $r = 8.96$ lbs per ton in order to allow for the variations of the speed (which at the same time did not exceed 19 miles an hour), of the curves, and of the gradients, the influence of which is not completely eliminated by the double journey, we get $O = 44.12$ lbs per ton, and $E = 0.60$.

346. M. *V. Grimburg* in 1860 (*), and M. *Bauschinger* some years later (**), made interesting experiments already mentioned (163), and which were to have included the determination of the resistance proper of the engines; but that part of the programme was not able to be carried in either case.

For M. *V. Grimburg*, then attached to the company of the Austrian State lines, the question was not to establish a comparison between the types of engines forming the stock of those lines.

The mode consisted in dealing with a single engine, different elements of which were varied; so that it represented successively the types in question, and which differed chiefly in details.

This engine was fixed in a framework, the wheels lifted up, and the boxes keyed up, in a workshop (Pl. XVII, *fig.* 1). The influence of the variable and appreciable influence of the atmospheric conditions, and that of the state of the permanent way were eliminated; besides the pressure, the admission, the speed, the angle of the eccentrics, and the lap were made to vary.

The work on the pistons was given by two indicators (163); the work on the axle was to be given by a *Prony's* brake applied to each of the driving-wheels, and the blocks of which *s*, *s*, took hold of the tire and the flange: one of these brakes was kept to a constant tension. It was in acting on the other that the resistance was made to vary, that is to say, the total friction on the tires, and consequently the velocity.

Instead of obtaining equilibrium, and consequently the moment of the friction, by means of a weight, it was thought simpler to apply to one of the blocks s a frame *m n p* butting on the table of an ordinary weighing-machine BB, for registering the pressures. A counter gave the speed, the weighing machine ought to have given the effort, and consequently the

(*) *Mittheilungen über die mit der Maschine Leopoldstadt in Temesvar angestellten Versuche*; pamphlet 4to, *Vienna*, 1862.

(**) *Indicator-Versuche an Locomotiven*, pamphlet 4to, *Leipzig*, 1868.

work available on the wheels; but as is easy to see, that instrument was not sensitive enough. In reality, the part played by the apparatus was reduced to a simple ordinary brake, allowing the resistance and the speed to be varied, but giving no measure of the first.

Thus restricted, the experiment exhibited the influence exerted by each of these variable elements, not on the effective work of the engine, but on the work recorded by the indicator, or acquired by the pistons. This was looked on as sufficing for the principal object of the experiments, because it had been admitted, gratuitously enough, that the work of the resistance of the organs is in constant ratio to the work on the pistons.

The series of experiments made at *Munich* by M. *Bauschinger*, very complete, at the same time, as experimental study of the distribution, could not give the measure of the resistance on the coupling-bar, or want of a suitable dynamometer; it thus presents, in this respect, the same hiatus as the preceding.

The extracts we think well to make from this interesting work, as well as from the preceding one, will come better in the following chapter.

347. *Resistance of engines to starting.* We have already said (III, 211; II, 293) that a special friction at starting is possible, at least for certain states of *lubrication* of the bearings, modified by prolonged standing. MM. *Vuillemin*, *Guébhard*, and *Dieudonné* cite the following figures (*), obtained by drawing heavy engines by a small uncoupled engine.

		lbs	
1st,	Mixed engine : type 14, with its tender.	35.05	per tons.
2nd,	Engine with 6 wheels coupled, type 15, with its tender. .	43.43	do.
3rd,	do. 8 do. (**) do. . .	66.14	do.

The two first startings are stated " easy "; but, as we have already said (II, 211), real starting does not admit of any qualification.

" We have observed ", say the authors, " at the starting of a mixed engine, an effort going up to 88 lbs, notwithstanding which, the starting could not be said to be abrupt. Every day, in railway service, similar startings are made. "

Unquestionably, and often couplings are broken.

After discussing the experiments of the engineers of the Eastern of France on several occasions, is it necessary to add that no one, far less their

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(*) *De la résistance, p.* 14.
(**) *Ditto.*

authors, will misunderstand the motives of some criticisms we have had to make. They were the expression of the importance which we attach to this remarkable series, to the difficulty and merit of which we render full justice, and which has been welcomed in France and abroad with an unanimous sentiment of interest.

348. *Resistance due to curves.* Curves evidently increase the resistance of the engines more than that of the waggons, on account of the greater wheel-base, and their absolute parallelism.

This resistance is shown, particularly, by the rapid thinning off of the flanges of the leading-wheels, on which is applied, every moment, the effort which produces the deviation. In the new engines with eight 3.48 feet wheels on the Austrian Sud-Bahn, in which the driving-axle is the third, the two first pairs of wheels can change positions with each other. The tires are thus made to last double as long. Failing special experiments on the engines, we have nothing to add to what we have said of curves on the subject of waggons.

CHAPTER III

DETERMINATION OF THE WORK YIELDED BY THE MECHANICAL THEORY OF HEAT.

§ I. — Expression of the calorific yield.

349. In order to be complete, the study of a thermal engine ought, at the present day, to be based on the mechanical theory of heat, which is as necessary to engineers, as that of the resistance of materials. Its principles are set forth in many books, irreproachable as scientific works, but in which the application to actual engines is too often treated with regrettable inconsiderateness, and marked with serious errors.

While supposing known, as we have already done (book IV, chap. III), the principles of a branch of mechanics which should be familiar to every one, we shall not neglect the opportunities which may offer, for rendering the understanding of it more precise and clear and we shall make it our study particularly to do away with or to explain the apparent disagreements between the theory and the facts observed in engines.

We shall not, at the same time, lose sight of the fact that it is with locomotives we are dealing in this work; and if we cannot dispense with seeking for examples and instruction in the examination of other types, we shall do so with the moderation due to the special character of this book.

350. In spite of the identity of nature between heat and mechanical work, of the *vis viva* of calorific vibration and the *vis viva* of mass, the passage from the first state to the second can only be realized for industrial purposes by periodical changes of volume, or in general, of *the state* of a body placed successively in connection with two sources of heat, main-

tained at different temperatures. In order to transform heat into work in a continued manner, the homogeneous body, the expansion of which under pressure develops the work, takes heat from the hot source, cedes a portion to the cold source, and returns to its primitive state, having transformed into work, *at the most*, the excess of the heat taken from the first source, over that yielded to the second.

In whatever manner these changes take place (we shall return to this) whether the conditions of the maximum of work yielded, be farther or nearer, Q and Q′ being the quantities of heat respectively taken from and yielded to the two sources, $Q - Q'$ is the heat utilized, and $\frac{Q - Q'}{Q}$ is the yield.

Example cited by M. *Regnault* : " In all cases ", says M. *Regnault* (*), " the quantity $(Q - Q')$ of heat utilized as mechanical work will only be a very small fraction of that (Q) which it has been necessary to communicate to the boiler (hot source). In a steam-engine with complete expansion, without condensation, into which the steam rushes under a pressure of 5 atm. and goes out under the pressure of the surrounding atmosphere, the quantity of heat possessed by the steam on its entrance, is, according to my experiments, about 1175 (F°) units; that which it retains at its exit is 1146 units. According to the theory which I have set forth " (the mechanical theory of heat), " the quantity of heat utilized would be $1175 - 1146 = 29$ units, that is to say 0.025 of the quantity of heat given to the boiler. "

The position of a locomotive at 5 atmospheres, would be more unfavourable still in certain respects, as the valve-motion does not permit the expansion to be pushed to the theoretical limit, the pressure of the atmosphere.

M. *Regnault* supposes the feed-water at 32° F; as it is at least at 40°, the heat to be furnished is 1156, and the yield is expressed by $\frac{29}{1156}$ instead of $\frac{29}{1175}$, but this difference may be neglected.

351. The preceding estimate had given rise to many observations : some, tending rather to diminish the impression it produced than to attack it in itself, others, rejecting it, apparently in the name of facts and principles. We shall come back to the first farther on; let us at present dwell a little on the second, which are mainly based on a serious error which we shall find often cropping up, and which it is right to point out at the very beginning.

In order to give an idea of the enormous loss of heat experienced in steam-

(*) *Relation des expériences.* vol. II, Introduction, p. II.

engines, M. *Regnault* took an example, both simple and striking. He made a supposition, the simplest possible, like an infinity of others; he supposed that the steam, entering at the temperature T, saturated and dry, went out, still saturated and dry, at the temperature T'. This was, I say again, a particular example, nothing further, and it could be nothing else. It was a matter of course; better perhaps, however, to have said so.

If thanks to M. *Regnault's* labours, the value of Q results directly from the weight and the temperature T of the dry saturated steam, it is quite another thing as regards Q', and consequently the ratio $\frac{Q - Q'}{Q}$. If theory has been able to give a very simple expression Q, of the work yielded by a apparatus forming a *Carnot's cycle*, an apparatus which is not however completely realizable in practice, — it is because every thing therein is completely determined; — and for every real cycle, going from *Carnot's* cycle, the work yielded differs in a greater or smaller degree from, but is *always less* than the yield of the theoretical cycle.

" It is very nearly in these terms " (referring to the passage reproduced above), says M. *Verdet* (*), " that M. *Regnault* has drawn up a criticism of the steam-engine, which has been repeated everywhere, and which seems to have placed among the number of the crudest apparatus, the most powerful of our industrial motors. "

Verdet cites afterwards four examples of condensing engines, for which the yield, calculated in M. *Regnault's* way, would be on the average 1/19th, while by experience, M. *Hirn* has found 1/8th.

Verdet sees in that a manifest contradiction (**), the opposition of two rival « theories », between which a choice has to be made; and the choice according to him, cannot be doubtful.

In what then is there a « *contradiction* »? Where is there « *opposition of theories* »? Nowhere. M. *Regnault* arrives at a figure, starting with a particular supposition; one must of course be made, in order to arrive at a numerical result. M. *Hirn* arrives at another figure, more satisfactory, by dealing with actual engines, with *superheated steam*. What are we to conclude (for we have no idea whatever of putting M. *Hirn's* figures in question), unless it be that the supposition of the one was not realized in the engines with which the other dealt, or, more generally that things took place therein in a different and much less simple manner, in which there

(*) *Théorie mécanique de la chaleur*, 2nd lesson, vol. I, p. 4. — *Paris, Victor Masson*, 1868.
(**) " *Thus*, he says, *the contradiction is complete*, " p. 57.

is nothing but what is perfectly natural, for coincidence would have been a very remarkable chance?

But instead of drawing this conclusion, *Verdet* condemns, as essentially false and contrary to principles, M. *Regnault's* calculation. The decided superiority of the figures obtained by M *Hirn*, takes, in his eyes, one scarcely knows how, the character of a fact, general, necessary and applicable to all engines. And what grounds has he for laying down this principle? A secondary fact, interesting in itself, by the remarkable confirmation which it brings to the mechanical theory of heat, that is to say, the *partial condensation* which is produced under certain conditions perfectly determined, that of a *dry* vapour expanding without *any addition* (*) *of heat*.

It has become a sort of axiom, and we hear it continually repeated that, everywhere and always, a portion of the steam condenses in the cylinders of engines, *during the expansion*. Now, it is precisely the contrary which takes place in the engines most used : it is not a *condensation*, but an *evaporation* which takes place. We shall see the proof of this farther on.

There would in effect, as is pretended, be a *condensation during the expansion* : 1st, if the steam were dry, to begin with; 2nd, if the steam did not go down during the admission, on the sides of the cylinder; 3rd, if, lastly, the expansion were effected within bounds impermeable to heat, if it were, according to the expression adopted, an adiabatic expansion. But these theoretical conditions (those, as we shall see (357), of *Carnot's cycle*) are very far from those of the most part of *actual* engines. The steam admitted is not dry, but moist, and sometimes very moist. The sides of the cylinder, clothed with moisture, are very far from having the passive character assigned to them by theory.

Difference in this respect between engines with one and with two cylinders. It is quite understood, in order to avoid all misunderstanding that we are here dealing with single-cylinder engines. There is in effect a main difference between the thermal phenomena which are effected in one engine, working with expansion, according to whether it has one cylinder or two. In the first, the sides *yield* heat to the steam, during expansion or during a portion thereof; in the second, the sides of the *large* cylinder *take* heat *from* the steam, which they find at a much higher temperature than their own (**). Altogether, in engines with a single cylinder, *the quantity of*

(*) It is needless to add : " or *subtraction* ", the vapour which does not remain saturated if no heat is added to it, can do so still less if heat be taken from it.

(**) *Hirn, Exposition analytique et expérimentale, etc.*, vol. II, p. 53. *Paris, Gauthier-Villars.*

steam contained in the cylinder at the end of the expansion, far from being less than at the commencement, is greater, and often much greater.

We thus see what is *Verdet's* error, when he says (*):

" *The condensation during the expansion is thus the physical mechanism to which the steam-engine owes the greater part of its motive power.*

We shall shortly see this imaginary mechanism very differently appreciated by the same author.

Farther on (**) he returns to the charge in these terms:

" The *condensation* of a part of the steam *during the expansion*, plays an extremely important part in the steam-engine, and makes of it a motor which does not deserve the reproach of extreme imperfection conferred on it by M. Regnault. "

The author of a work (***), interesting and instructive, by the way, like that collected by *Verdet's* pupils, M. *Briot*, has drawn inspiration mainly from the doctrines of that much to be regretted scientist. It is thus not surprising to find therein, and in a more marked form still, the error we point out. It is therefore the more necessary to dwell on it.

" It was not known formerly ", says M. *Briot* (****), " that the steam condensed, in engines working with expansion, and results were arrived at, as to the yield of these engines, completely erroneous. Suppose that a cylinder receives *saturated* and *dry* steam, and that the communication with the boiler is closed when the piston has only arrived at a portion of its stroke. The steam expands, one portion *is condensed* and disengages, in condensing, heat which is transformed into work. *This is the principal source of the work of these engines.* "

We shall put the facts straight by an examination of actual engines. But it was necessary to put the reader on his guard against the consequences of this confusion between a fact of purely theoretical bearing, and the phenomena, quite different, indeed almost always opposed, which really take place in the engines most adopted.

352. But there is more: let us admit, for a moment, the reality of the *condensation* during *expansion*, as a general law. In what way would that explain the superiority of the figures obtained by M. *Hirn*, over the estimate made by M. *Regnault?* If this condensation is definitive, very well; the heat abandoned by the water is taken up; but if that water, condensed during the expansion is evaporated afterwards, that is to say during the period of

(*) *Théorie mécanique*, vol. II, 2nd lesson, p. 58.
(**) *Théorie mécanique*, vol. II, 2nd lesson, p. 252.
(***) *Théorie mécanique de la chaleur*. 1 vol. 8vo. *Paris, Gauthier-Villars*, 1867.
(****) *Ditto.*

escape or of condensation, what becomes of the pretended advantage. It changes to a disadvantage, and the greatest of all, as we shall soon see!

Altogether, this fact that is presented as the *principal source of the work in engines*, is almost always imaginary; and, were it real, it would prove absolutely nothing; nothing could be concluded from it. It would never be anything but a simple detail, one of the forms of the mutual and continual action between the steam and the sides, teaching absolutely nothing touching the series of ulterior phenomena and their final result.

353. Whatever may be the slightness of the final calorific yield, estimated independently of the more or less unfavourable conditions without which the transformation of the heat into work is effectively possible, it would be very wrong to conclude from the smallness of this figure, that steam-engines are extremely imperfect. This would be at once to misunderstand the importance of the progress accomplished at the cost of such efforts, and to excite for the future, hopes probably chimerical.

In order for the yield $\frac{Q - Q'}{Q}$ to reach unity, it would be necessary for Q' to be nothing. Now the heat $(Q - Q')$ transformed into work, by the only process at our disposal (350), can never be but a fraction, variable, but very small, of the heat (Q) taken from the hot source; the mechanical theory of heat assigns, and that is not one of its least services, the limit which this fraction cannot exceed nor even reach; we shall shortly indicate it (358).

An engine reaching that limit, however small it might at the same time be, would be *perfect*. At a period when the principles of the theory, scarcely in their infancy, had not the authority which they have acquired by so many confirmations often unexpected, the most enlightened and most progressive spirits could not make up their minds to accept that position. To dispose of a quantity of heat Q units which represents, which virtually *is* a quantity of work of 772 ft pds (F.) Q (*), and to be able only to carry

(*) The figure 770 or 772 is generally admitted. Its exactness is sufficient for the applications and there is no need, from that point of view, to consider the discrepancies presented by the different values given by experiment.

But from the point of view of principles, on the contrary, it is of consequence to bear in mind the observations presented by M. *Regnault*. The discrepancies in question are not only the expression of the unavoidable errors of experiment; they are also in relation with the nature of the substances operated on.

"The mechanical equivalent of heat, says the eminent physicist (*a*)," is necessarily a theoretical constant. In order to obtain its exact value by the experimental method, a *perfect* gas should be operated on, that is to say, a gas following rigorously Mariotte's law, having a constant coefficient

(*a*) *Relation des expériences*, 1870, vol. III, page 572.

the transformation to a very small fraction of Q units of heat, that seemed hard.

If it cannot be affirmed that there is an absolute impossibility of finding a mode, an agent so to say, of transformation less burthensome than the fall of heat, what is certain, is, that up to the present time, no other is known. Is the blame to be laid on the alternate movement of the piston? Would things be improved by the applying the power always on the same face of a piston animated by a continuous movement, that is to say by the principle of the rotary engine, too often tried, and with so little success? In no way. The condition of the fall of heat is independent of the details of the mechanism, it bears on the engines, the piston of which has a continuous or circular movement, as much as on those the piston of which has an alternate rectilinear movement.

354. *Attempts of the* Elder Séguin. In the number of those who could not see in the slightness of the yield an inexorable necessity, was the *elder Séguin*, of a penetrating and investigating mind, endowed with an equal aptitude for the divers branches of the engineer's art, and who in applying his brilliant abilities to all, had escaped the usual influence of too narrow specialities, of too limited horizons.

In 1857, he published under this title: *A Memoir on a new system of motor working always with the same steam, to which is restored, at each stroke of the piston, the heat which it has lost in producing mechanical effect* (*), a work

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of dilatation under all pressures, and the specific heats under constant pressure and under constant volume, c and c_1 and $K = \frac{c}{c_1}$ are constant for all pressures and under all temperatures." But if the atmospheric air be operated on, or one of the gases called *permanent*, we obtain a value ε differing more or less from the theoretical equivalent E. In all cases, we may put $E - \varepsilon = \varphi(p, v, t)$; $\varphi(p, v, t)$ being a fonction of the parameters which vary for the different gases. It may be regarded as representing the quantity of work expended internally in the material gas in order to effect the movement of the molecules (internal work), a work which is nil in the *ideal* fluide.

To sum up, the theoretical equivalent E is a limit; the values ε we may deduce from the real gases, will approximate all the more nearly to it, as our experiments realize the conditions under which the gas diverges the least from the *ideal* fluid.

M. *Regnault's* experiments on atmospheric air lead, all corrections made, to values which oscillate about 795 foot pounds.

M. *Hirn* (*a*) is disposed to look on 787 as the most correct. He does no dissimulate personal grounds for this preference, which is perfectly legitimate, however, as he is better acquainted than any one with the care with the experiments (friction of water); but as M. *Regnault* remarks, the influence of the substance, other than a permanent gas, is inevitable

(*) Pamphlet 4to. *Paris, Mallet-Bachelier.*

Exposition analytique, vol. I, page 115.

which deserves to be kept, like every thing else from his pen, were it only as a proof of the sort of strain undergone at times by the ablest minds, in order to get resigned to the condition of the transformation of heat into work. The demonstration of the equivalence of heat and mechanical work seemed to warrant many dreams; it has caused, in this way, more than one deception. It is certain that, speaking industrially, the *equivalence* does not exist.

Let us bring to mind only the commencement:

" I had the honour to inform the Academy, the 3rd of January 1855, of the project which I had conceived of the construction of a steam-engine on the new principle I have put forward, according to which caloric and movement are the manifestations under different forms, of one and the same cause, and *of the possibility which I, in a measure, foresaw, of attaining the point of only expending in order to produce force, the quantity of heat strictly representing the mechanical effect obtained.*

" It is known, in effect, that in steam-engines, such as they are employed for industrial purposes, use is made of steam in the saturated state, and that it is driven off into the air, or condensed by crushing its energy after having made use of it, losing thus all the heat which was necessary in order to reduce it into steam. Now, as the quantity of heat employed to reduce the water into steam, is very considerable, with reference to that which is necessary to raise its temperature afterwards, and consequently augment its energy, I have concluded therefrom that if we could manage to construct an engine, in which the same steam should always be made use of, in restoring to it, at each stroke, the quantity of heat which has been transformed into mechanical work, an enormous loss would be avoided, and we should so arrive at only expending strictly the quantity of heat and consequently of fuel representing the force produced."

After some details on his preliminary trials, M. *Séguin* added (*) : *It resulted for us from the whole of these experiments that it was possible to use the steam as an intermediate between heat and force and that it was sufficient for this purpose to make it pass, by means of* SUCCESSIVE EXPANSIONS AND CONDENSATIONS, *through various states of tension and temperature.*

If these terms, vague enough, by the way, allowed a glimpse of the *ways* and *means*, it most certainly was not of the application of a new principle.

And in effect, M. *Seguin's* efforts, and those of the able constructor to whom he confided the realization of his ideas, M. *Farcot* senior, ended in an apparatus which, without reckoning the accessory use of a very high degree of superheating, had for essential elements, a boiler and a condenser, that is to say, the two sources of heat. The inventor was thus brought, in spite of himself, to confront the necessity common to all steam-engines, the *fall of heat.* No fall of heat, no work.

(*) Memoir cited, page 11.

Although his paper seemed to breathe great confidence in his success, M. *Séguin* afterwards gave up his researches, in spite of the tenacity which, no less than the intelligence, had resisted in him the attacks of age.

He had become aware, without doubt, that, whatever may be done, it is impossible to avoid the *fall of heat*, and its consequences; that it is not every thing, that indeed it is very little, to employ " *always the same steam* ", and that not only must the heat be restored, " *which has been converted into mechanical work* ", but also, which is a very serious matter, *the heat which the steam has ceded to the cold source.*

355. *Estimate of the yield* $\frac{Q-Q'}{Q}$. Let us return to the expression $\frac{Q-Q'}{Q}$ of the yield. The determination of Q and Q′ is neither simple nor very exact. The indicator diagram gives the mean pressure and the volume of the steam admitted into the cylinder From this is deduced, supposing it saturated and *dry* (*), its specific weight, its absolute weight and consequently the heat Q introduced into the cylinder. The heat Q′ carried away by the steam after its work on the pistons may be estimated in condensing engines by the method pointed out, long since, by M. *Hirn*, and which is known in England as Farey's method. It consists in gauging the water leaving the condenser during a given time, and measuring its rise of temperature in passing into the condenser.

Besides, the measure of Q, combined with the squaring of the diagram of work, would be enough.

Let us take up again the general equation (113, p. 240) :

$$dQ = dU + Apdv,$$

wherein A is the calorific equivalent of work $\left(\frac{1 \text{ unit of heat}}{772} \text{ or } \frac{1 \text{ unit of heat}}{774}\right)$, and U the internal heat.

It gives :

$$Q - Q' = U - U' + AS,$$

S being the difference between the power applied on the two faces of the piston.

For a whole number of revolutions the substance has returned to the same state :

$$U = U';$$

(*) Special precautions must be taken as was done by M. *Hirn* in his experiments on *stationary engines*, in order that it may be so; with locomotives, success would be difficult to attain.

whence

$$Q - Q' = AS \text{ (*)} \quad \text{and} \quad \frac{Q - Q'}{Q} = \frac{AS}{Q}.$$

It is by the relation (*a*) that M. *Hirn* determined, inversely, the mechanical equivalent of heat $E\left(=\frac{1}{A}\right)$ by dealing with powerful steam-engines: a mode of observation full of interest in itself, but scarcely suitable for the exact determination of the *equivalent*.

The expression $\frac{Q - Q'}{Q}$ thus requires operations too laborious to be of use in regular practice.

Thus, although it is the real measure of the calorific yield (provided that Q and Q′ *are* the quantities of heat taken from one source and ceded to the other), it is not that expression that is made use of when a brief estimate is wanted, but this one : $\frac{T - T'}{T}$, in which T and T′ are the *absolute* temperatures (113) of the two sources (or more exactly of the substance while it is in communication with each of them), that is to say the temperatures given by the air-thermometer augmented by $\frac{1}{\alpha}$, α being the coefficient of dilatation of perfect gases : $\frac{1}{492}$ (**).

But it is not at all a question of an identity; $\frac{T - T'}{T}$ expresses the yield under certain perfectly defined conditions, from which actual engines depart always more or less, but are *always below*. It is a limit, which the real yield $\frac{Q - Q'}{Q}$ may approach, but which it can never reach, and from which it is frequently far off.

Let us establish the value of the limited yield.

§ II. — Cycles in general.

356. Without taking up some new denominations scarcely necessary,

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(*) The values obtained thus by M. *Hirn*, varied according to M. *Briot*, from 546 ft pds to 1092 ft pds, and according to *Clausius*, the mean was 752. M. *Verdet* (a) rectifies these figures and points out as exact mean of 9 experiments: 725, with 645 and 1102 as extreme values.

(**) The absolute zero, or 273° of the air-thermometer, is the point to which corresponds the *total* extinction of the calorific *vis visa* of gases, or the *total* exhaustion of the heat they contained.

and brought in rather hastily into the mechanical theory of heat, let us define the term *cycle*, which is repeated every moment therein.

The state of a homogeneous body is regarded as completely defined, by its specific volume v, its temperature t, and its superficial pressure or tension p. Two of these quantities determine the third. The state of the body is thus represented by a function : $\varphi\ (v,\ t,\ p) = 0$, unknown, unless for the perfect gases, for which it reduces to the very simple law of *Boyle* and *Gay-Lussac* : $p\,v = \mathrm{R}\,(460 + t) = \mathrm{R}\,\mathrm{T}$ (113).

By the word *cycle* is designated the series of successive states by which a body passes from one state p, v, t, to another p', v', t'. The cycle is perfect, if there is never any deviation accomplished between the elastic force of the body and the pressure exerted on it, between its temperature and that of the substances with which it is successively in communication in the course of its evolution.

This condition is that of the *maximum yield* of the cycle, between two temperatures t and t'; it is also the condition of its reversibility, that is to say that, if the body repasses through the same phases, but in a contrary way, from t' to t, it exerts or receives at each moment an elementary work equal and with contrary sign to that which would correspond to the same *state* in the direct way; so that the total work corresponding to the two evolutions, direct and reverse, is *nil*.

The *cycle* is *closed* if the body returns to its initial state v, p, t; having for its own part neither taken nor ceded heat in any shape, it has only been a simple vehicle, distributing the heat it has received from the hot source into two parts : one which it transforms into work, the other which it gives up to the cold source.

This is easy to represent graphically (Pl. XVII, *fig.* 2). $0a$ being the specific volume v of the body and aA its pressure at the same moment, the point A of the plane $y\ o\ x$ represents its state, and the series of points M, M'....., having for abscissas the volumes and for ordinates the pressures, represents in the same way its successive states; the external work $\int p\ dv$ of the body, expanding from $0a$ to $0b$ and equivalent to the heat transformed into work, is measured by the area a AMB b.

If the body (*fig.* 3), after expanding from the volume $0a$ to the volume $0b$, contracts, repasses through the same series of less volumes to pressure (and consequently to temperature) α N, α N'...., and returns at the same time to the same volume $0a$, to the primitive temperature and consequently primitive pressure, the cycle closes at A; and the area A ab BNN' measures the work exerted on the body during its compression. The dif-

ference of the two areas, that is to say that circumscribed by the two curves, measures thus the heat transformed into work during the performance of the cycle.

§ III. — Of *Carnot's* cycle. — Its yield.

357. *Carnot's cycle.* This is the particular case of the perfect and closed cycle, in which the number of the sources of heat is reduced to a minimum, that is to say to two. The intermediate body thus passes through the following four phases (*fig.* 4):

1st. It is placed at first in communication with the hot source T; it is allowed to expand at constant temperature T, from the volume O*a* to the volume O*b*;

2nd. The communication with the source is then interrupted. Isolated at the same time from both the sources, and contained in a envelope supposed impermeable to heat, the body expands from the volume O*b* to the volume O*c*, its temperature sinking, seeing that, in that expansion, it overcomes a pressure, and produces external work;

This expansion without addition or subtraction of heat, or adiabatic, is continued in virtue of the fundamental principle of the perfect cycle (356) until the temperature of the body goes down to T′, the temperature of the cold source, the communication not taking place until that equality is reached.

3rd. This communication established, the body is compressed at the constant temperature T′, giving up at each moment to the source the heat corresponding to the compression. This third phase lasts until the body has contracted from the volume O*c* to the volume O*d*, determined by the condition that at the end of the following and last phase, the body may be brought to its initial volume O*a* and its initial *state* A;

4th. This volume O*d* being arrived at, the communication with the source T′ is in its turn cut off, and the body contained always in a capacity which can neither give to nor take heat from it, is brought back, by *adiabatic* compression, along the line D A, which closes the circuit. Thus reconstituted, the body is ready for another evolution, and so on, indefinitively, as long as the two sources are maintained at the same temperatures T, T′. The complete circuit is thus composed of four lines: 1st, two *isothermal* curves, corresponding, the one AB to thec ommunication with the hot source, the other CD to the communication with the cold source (or, in usual terms, the one to the full admission of the steam, the other to its escape, either into

the atmosphere); 2nd, two *adiabatic* curves, corresponding, the one BC to the expansion, the other DA to the compression, without loss or gain of heat, of the imprisoned steam.

The area circumscribed by these curves, that is to say the heat transformed into work (including the losses that theory neglects), presents considerable analogy with the diagrams, taken off, by means of the indicator, from the cylinders of actual engines. It is in effect, as is easily seen, because the conditions of *Carnot's cycle* are realized more or less in engines: completely enough for the phenomena which take place on the *motor* face of the piston, less so for those which take place on the *resisting* side. We shall moreover return to the points common to the two cycles, the one theoretical, the other real, and to their divergences.

The question for the present is to establish the yield of the first, which is, as we have said, *the limit* of the yield $\frac{Q - Q'}{Q}$ of actual engines working between the same limits T, T′, of temperature.

358. *Case in which the intermediate body is a perfect gas: simple expression of the yield.* Let us suppose at first that the intermediate body, which forms under the conditions defined just now, the shuttle between the two sources of heat, is a *perfect* gas, for which the relation (113) has been established

$$dQ = dU + Apdv = c_1 dt + Apdv,$$

in which c_1 is the specific warmth with constant volume of the gas; because $p = \frac{RT}{v}$ (113), we have

$$dQ = c_1 dt + ART\frac{dv}{v}.$$

Let us apply this relation to *Carnot's* cycle.

(*a*) 1st. *isotherm* AB (*fig.* 4) (dilatation from v to v_1),

$dt = 0$ gives: $\quad dQ = ART\frac{dv}{v} \qquad Q = ART \log. n \frac{v_1}{v}$

(a value already established (113));

it is heat taken from the hot source.

(*b*) 1st *adiabatic* (expansion) BC (dilatation from v_1 to v_2),

$$dQ = 0 \text{ at each instant;} \quad \text{whence: } \frac{c_1 dt}{T} + AR\frac{dv}{v} = 0,$$

and because $dt = dT$, $c_1 \log. \text{nat.} \frac{T}{T'} + AR \log. \text{nat.} \frac{v_2}{v} = 0.$

(*c*) 2nd *isotherm* CD (contraction from v_2 to v_3), $Q' = ART' \text{ log. nat. } \frac{v_2}{v_3}$: this is the heat yielded to the cold source.

(*d*) 2nd *adiabatic* (compression) DA (contraction from v_3 to v),

$$c_1 \text{ log. nat. } \frac{T}{T'} + AR \text{ log. } \frac{v_3}{v} = 0.$$

(*a*) and (*c*) give $$\frac{Q}{Q'} = \frac{T}{T'} \frac{\text{log. nat. } \left(\frac{v_1}{v}\right)}{\text{log. nat. } \left(\frac{v_2}{v_3}\right)},$$

(*a*) and (*c*) give : $$\text{log. nat. } \left(\frac{v_2}{v_1}\right) = \text{log. nat. } \left(\frac{v_3}{v}\right), \text{ or } \frac{v_1}{v} = \frac{v_2}{v_3}$$

then : $$\frac{Q}{Q'} = \frac{T}{T'}, \text{ whence : } \frac{Q - Q'}{Q} = \frac{T - T'}{T}$$

The expression $\frac{Q - Q'}{Q}$ may thus in the particular case of *Carnot's cycle* be replaced by $\frac{T - T^{(*)}}{T} = \frac{t - t'}{273 + t}$ which only includes the extreme temperatures.

The relation $\frac{Q}{Q'} = \frac{T}{T'}$ is only a particular case for *Carnot's* cycle of the general relation $\int \frac{dQ}{T} = 0$ established by *Clausius* for any reversible cycle; dQ is the infinitesimal quantity of heat, positive or negative, which the body exchanges, at the moment when its absolute temperature is T, with the body with which it is in contact at that moment, and the temperature of which only differs from T by a quantity infinitely small.

359 It is easily shown that the yield $\frac{T - T'}{T}$ is the greatest that can be given by a closed cycle working between two extreme temperatures, T, T'. Other cycles may reach the same limit, but none can exceed it. We shall admit this point.

360. We shall admit also that the relation $\frac{Q}{Q'} = \frac{T}{T'}$ proved for a *Carnot's cycle run by a perfect gas*, can be extended to any body. So generalized, this relation constitutes *Carnot's principle*, which, with the principle of *equivalence*, unknown to *Carnot* (he admitted that $Q' = Q$, that is to say that

(*) The sum $\int \frac{dQ}{T}$, taken for any portion of the cycle, is what *Clausius* calls *Entropy*. For a whole cycle, the entropy is *nil*. For a non-reversible cycle, $\int \frac{dQ}{T}$ is always < 0.

the work resulted from the simple fact of the *transfer* of the heat) forms the basis of the mechanical theory of heat.

361. This extension is permitted, for its negation would lead to very unacceptable consequences, while those of its affirmation are, on the contrary, very probable. In extending to steam for example, the principle demonstrated in respect of air, we make one of those generalizations which are perfectly legitimate so long as they do not encounter any fact incompatible with them.

The calorific yield of a *Carnot's* cycle between the extreme temperatures T, T′, has thus for expression $\frac{T-T'}{T}$; and the yield is less, between the same limits of temperature, for every cycle departing from the theoretical conditions.

Q being the heat furnished by the hot source to an actual engine, the quantity converted into work cannot reach the value $Q\,\frac{T-T'}{T}$, and the work itself has for limit: $\frac{Q}{A} \times \frac{T-T'}{T}$.

362. T and T′, — it is well to insist on this point, — only designate the temperatures of the two *sources* when the theoretical conditions are fulfilled, that is to say, when the body has itself exactly these respective temperatures, at the moment when the two communications are established, and during their continuance. It may happen (in fact, it almost always does so even) that the body receives the heat from a source the temperature of which is higher than that which it possesses on the first isothermal curve, and cedes it to a source the temperature of which is on the contrary lower than that which it possesses on the second isothermal curve.

The relation $\frac{Q}{Q'} = \frac{T}{T'}$, exists, but T and T′ are then, not the temperatures of the sources, but those of the *bodies themselves.*

The cycle always exists, but with a *deviation* of temperature reduced by a fall at each source (fall from the boiler to the cylinders during admission, fall from the cylinders to the condenser during the exhaust). T diminishes, T′ increases, and on that double ground, the yield $1 - \frac{T'}{T}$ diminishes. The area which measures the work gathered, is reduced at the same time by the lowering of the upper isotherm, and by the raising of the lower one.

Locomotives, for example, have the atmosphere for condenser; does this signify that, the mean temperature of the atmosphere being about 40° (F), the value of T′ is in that case $460 + 40 = 500°$ only?

Evidently not. Even supposing the expansion pushed to its theoretical limit, the steam, when it is discharged, has for pressure that of the atmosphere, and consequently, for temperature at least 212°, if it is saturated, and more if it is not (that is to say if it is superheated); so that

$$T' = 460 + 212 = 672^{\circ} \text{ at least.}$$

For the example taken by M. *Regnault* (350), we thus have:

$$T = 460 + 305 = 765^{\circ},\ T' = 460 + 212, \text{ and } \frac{T - T'}{T} = 0.12,$$

a value which cannot even be reached: 1st, because the engine is far from realizing the cycle of maximum yield; 2ndly, because the theoretical yield neglects the losses of heat and work, which cannot be avoided.

363. *Advantages of high pressure steam.* For a locomotive with a maximum pressure in the boiler of 10 atmospheres (9 absolute), we should have

$$\frac{T - T'}{T} = \frac{144}{816} = 0.17.$$

that is to say a gain of nearly 50 per cent. Hence the advantage of high pressures.

The total heat necessary for converting into saturated steam at t°, 2lb of water, retaining the notations already employed: $\lambda = 1091.7 + 0.305\ t$ units of heat, and the heat contained in that steam is expressed by $1091.7 + 0.305\ t - A\ p\ u$, or again, by $q + \rho$ units of heat.

$q + \rho$ increases very little with the pressure, the diminution of the *latent internal* heat ρ compensating in a great measure for the increase of the *liquid-heat*, q.

M. *Zeuner's* table no. X (*), gives the values of q, ρ, and $A\ p\ u$,

	Units of heat.	Units of heat.	Units of heat.
At 5 ats (306.0), we have	$q = 276.7$	$5 = 818.9$	$q + 5 = 1095.6$
At 10 ats (356.6) do.	$q = 328.8$	$\rho = 778.9$	$q + \rho = 1107.7$

The increase of nearly 50 per cent of the yield, corresponds thus to an increase of $\frac{1}{100}$th of the quantity of heat.

If we took the total quantities of heat, above that of the water at 32°, necessary for the formation of the steam, that is to say including therein the external latent heat $A\ p\ a$, equivalent to the external work developed by the

(*) *Théorie mécanique*, page 584 and following.

formation of the steam under the pressure p, we should have : at 5 ats 1175.3 units, and at 10 ats 1190.7 units of heat. The increase, 15.4 units, again only represents a little less than $\frac{1}{76}$th.

The feed-water is never at 32°; there must be then subtracted, from q, the heat of the water at the temperature which it possesses, or 18 units, if it be at 50°, 180.9 units, if it be carried to 212° by the waste heat, as is done in locomotives (134), the heat (total) to supply afterwards to the boiler is : at 5 ats 994.4 units, and at 10 ats 1009.7 units; and the increase of 50 per cent of the yield corresponds to an increase of $\frac{1}{64}$th of the expenditure of heat.

364. *Remarks on the limit yield.* Although necessarily superior to the real value, this expression $\frac{T - T'}{T}$ of the yield is accepted with difficulty; it often is so unwillingly, with restrictions and reserves, turns of phrases which end in short, not in denying the slightness of the yield, but in establishing that it cannot be greater; which at least places the sagacity and talent of engine-builders completely out of the question.

" A false and very exaggerated idea is given, " says for example M. *Combes* (*), " of the state of imperfection in which our best steam-engines with high pressure and expansion, are still found by saying that they are only susceptible of utilizing 10 or 20 per cent of the mechanical work equivalent to the heat transmitted to the steam generators, according to whether they are provided with a condenser or not, even when the expansion is pushed in the cylinders as far as possible. *Without being absolutely charged with incorrectness*, this statement misleads those persons who entertain incomplete notions on the mechanical theory of heat, if care is not taken to add that it is impossible by any means, by the employment of any substance as an intermedium between two indefinite sources of heat, one of which would be at the temperature of the water contained in the generator, and the other at the temperature maintained in the condenser, to convert in a regular and continuous manner into mechanical work a fraction of the heat coming from the generator, notably greater than that which is so utilized by our most perfectly finished steam-engines; that the greater part of that heat necessarily passes off into the condenser; that the portion of the heat withdrawn from the boiler, converted, or rather convertible into work, is, according to *Sadi Carnot's* expression, so just and too often forgotten, proportional to the fall of heat. "

These developments tend, not to deny the reality of a enormous loss of heat, but to explain it on the contrary, and to show that it is inevitable. This loss, M. *Combes* recorded it in the preface (**) in these terms :

(*) *Exposé des principes de la théorie mécanique de la chaleur*, 1863. *Dunod, Paris*, page 144.
(**) *Exposé des principes*, etc., p. 1.

" The mechanical theory of heat brings to light the *enormous losses of heat* which take place in our most *perfectly finished steam-engines.* "

The author himself thus undertakes to establish the perfect justice of the idea, which he has elsewhere charged with incorrectness. More explicit still, touching the actual position, but more disposed to hope better from the future, M. *Redtenbacher* declared (*) « that improvements effected in existing engines could have no great effect, so long as a new way of utilizing steam and heat in general was not discovered. »

Like M. *Combes*, M. *Zeuner* set himself to free steam-engines from the reproach of imperfection laid to them, by showing not that this imperfection does not exist, but that it is inherent to the principle, inseparable from the current transformation of heat into work.

" It would be an error, " says he (**), " to take $\frac{Q}{A}$ for the available work, Q being the heat introduced.

The proprietor of a steam or a hot-air engine, is in the same position as the proprietor of a hydraulic machine. They only furnish their engines, in order to be utilized, with a certain *thermal weight*, or a certain weight of water, with an amount of fall rigorously determined $T - T'$, or $h - h'$. "

The assimilation established by M. *Zeuner* fails however in one point. For the work done by water or any other ponderable body, an amount of fall is inseparable from the weight. While if, in fact, a fall of temperature is indispensable in order to effect the continuous transformation of the heat into work, it is not the less true, that a quantity of heat Q represents by itself, and independently of every other element, of every other notion, a quantity of work $\frac{Q}{A}$; but what is also true, is that, while the complete utilization of the work $P \times h$ of a fall of water may be indefinitely approached in theory, it is not the same thing with the work $\frac{Q}{A}$ of heat, the maximum yield $\frac{T - T'}{T}$ being only able to reach unity for $T' = 0$, that is to say $t = 460$, absolute zero. The simple *transmission* of the work of the fall to a receiver, is effected under conditions much more favourable than the transformation into utilizable work of the heat equivalent to the work of that fall. The cooling

(*) *Der Maschinenbau. Manheim*, 1863, vol. II, page 592.

(**) *Théorie mécanique de la chaleur*, page 233.

requires, as well as the heating, an expenditure of work, that is to say of heat; the lowering of T′ is thus very limited. As to the increase of the deviation by the raising of T, this means is limited also, with steam, by the rapid progression according to which the pressure rises, when the temperature increases; at a moderately elevated temperature, 392° for example, the effective pressure reaches 9 ats and requires boilers of great solidity.

Some engineers, dreading the influence of high pressures, either with reference to leaks, or, as has already been said (335), with regard to the frictions of the machinery, withstand the general tendency; however, limited as one is in locomotives for the minimum temperature of the cold source, the elevated pressures must be accepted, under penalty of giving up increasing their power without augmenting their weight, and thus renouncing a better utilization of the fuel. This is what has been done, more or less resolutely, as we have seen by several examples; and experience proves that there is not much trouble in arranging the boilers for these new conditions.

365. *Superheated steam.* It seems easy at first sight, to get rid of the dependence between the temperature and the pressure of saturated steam, by heating it apart from its liquid, before making it act on the pistons; its temperature could thus be much raised, without exaggerating its pressure. But the use of superheated steam involves very serious objections; at equal pressure, it is injurious to the rubbing-surfaces, while saturated steam, or better charged with water, as it ordinarily is, renders the lubrication of the pistons and slides unnecessary up to a certain point. Fortunately, the constant action of the slides corrects, as we shall see farther on, that of the superheated steam, even heated to a very high degree.

The elevation of the pressure of saturated steam remains then the only method uncontested, but unfortunately restricted also in the application, of increasing the difference of the temperatures, and consequently the yield-limit.

Influence of superheating on the yield. We shall return (389) to superheating, on which opinions are very divided, but which receives too numerous applications for it to be classed, as is done by some engineers, among those apparent progresses which experience condemns. But let us make at once an essential observation: that, abstraction made of the difficulties of application, and of the drawbacks of superheating, a most incorrect estimate of its influence on the yield would be made by calculating it by the formula $\frac{T-T'}{T}$, simply substituting for T, the temperature of the steam in the

boiler, the temperature to which it is ultimately brought by superheating. The latter constitutes an abrupt change, a veritable *rupture* of the cycle, and the expression applicable to *Carnot's* cycle (admitting that it is a question of such a cycle, before the superheating) does not apply to the *real* cycle, modified by the latter.

The work $\frac{Q}{A}\frac{T-T'}{T}$ furnished by *Carnot's* cycle may be increased by an addition of heat π, made beyond the theoretical conditions. The addition may produce the same effect as a certain increase q' of the heat Q furnished by the hot source, but q' is always less than π.

366. *Influence of the temperature of the fire-box.* A great deal of importance is sometimes attached to the elevation of the temperature of the fire-box. It is evidently of main importance in a great number of applications of heat, but the position is different when it is a question of producing saturated steam, at a determined pressure, and consequently determined temperature.

In his interesting Official Report on the Marine at the Vienna Exhibition (*), M. *A. Friedmann* sets forth that, although marine engines are the most perfected of all, " their expenditure of fuel is always much more considerable than that of good locomotives. "

" As a matter of fact, " says he, " the expenditure of fuel in marine boilers is to that of locomotives as 130 to 100, by the double reason that the temperature is lower in the smoke-box, and higher in the fire-box of the locomotive than in the marine boiler. "

And he adds, on the subject of the ratio of consumption of fuel :

" This is easy to prove. The temperature is most frequently 1740° in the fire-box, and 572° in the smoke-box. Of the 1740° of heat produced in the locomotive, 1200° or about 68 per cent, get into the boiler, and 32 per cent are lost with the gases in the chimney. In marine boilers, the temperature of the fire-box exceeds rarely 1300°, and that of the escaping gases is almost always 700°, rarely 650°. In the most favourable case, of the 1300° of heat produced, 620°, that is to say only 50 per cent reaches the boiler, and the rest escapes by the chimney. "

The author afterwards points out the causes to which he attributes the less elevated temperatures in the fire-box of marine boilers and, consequently, the *greater expenditure of coal.* We shall not follow him into this discussion; we shall only remark that, notwithstanding the necessity, which

(*) *Rapport officiel*, etc. — *Vienne*, 1874, p. 76.

seems not to be contested, of an improvement in the conditions of the production of steam in marine engines, the consumption of these engines, in relation to the amount of work done, is very low, except perhaps in some cases. Often inferior to 2 lbs per horse *indicated* (that is to say measured on the pistons), it even goes down to 1.70 lbs (*).

If the reproach made by M. *Friedmann* in these terms :

" The consumption of coal in steam-boats is relatively very considerable, although their engine is the most complete steam-engine ever contrived. "

was founded, it is no longer so now.

A high temperature in the fire-box is useful, without doubt; it is at the same time a certain guarantee and an effect of complete combustion. It is favourable to the transmission of the heat, determined by the difference of the temperatures of the external and internal faces of the surfaces of the boiler. But if the fire supplies the hot source, it is not itself the hot source; it is the boiler, the temperature of which is fixed, not by that of the fire-box, necessarily more elevated, that is all, but by the pressure.

The maximum temperature, that is to say that of the complete combustion, effected with the quantity of air strictly necessary, and within sides impermeable to heat, would amount to for coal, according to *Peclet*, from 4.900° to 5.100°. If it were possible not to reach this point, but to approach much nearer to it than is done, it would have to be guarded against. The materials in contact with the fuel or the flame, and not cooled by their contact with the water on the opposite surface, would not resist, and the tenacity of the metals subjected to the pressure of the steam would be too much reduced. It is then indispensable to *dilute* the heat produced with an excess of air : a condition which, by the way, the stokers of stationary engines are only too ready to carry out, the treatment of a fire-box with a slight excess of air being hard and troublesome.

If besides, the motives by which M. *Friedmann* explains the economical inferiority which he attributes to marine boilers are hardly admissible, the importance of an elevated temperature is, within certain limits, incontestable; and from this point of view as from others, there would be a very great advantage in rendering the languid combustion in marine boilers more active (**).

(*) M. *Mallet. Étude sur les nouvelles machines marines*, page 3.

(**) M. *de Maupeou*, naval constructor, has inserted in the *Memorial du génie maritime* for March 1876, an interesting *study on marine boilers*. He brings out in this work, the considerable advantages which would be gained by the substitution of a forced draught for the natural

§ IV. — Investigation of the expansion and compression in a theoretical engine according to *Carnot's* cycle.

367. We have nothing to add to what we have said (357) on the first and on the third phase, the two *isothermal* curves. Not so however, as regards the *adiabatic* curves.

1st. *Expansion.* We have seen (113, p. 244) that the expansion of the air, without addition or subtraction of heat, is effected according to the law $\frac{p}{p_1} = \left(\frac{v_1}{v}\right)^k$, k being the ratio of the specific heats under constant pressure c, and constant volume, c_1. The equation of the adiabatic curve BC (Pl. XVII, *fig.* 4) is thus : $pv^k = p_1 v_1^k$, and it has for asymptotes the axes of the coordinates. For perfect gases, $k = 1.41$ or more exactly 1.408, according to *Rankine* (*). But M. *Regnault* has proved that *Boyle's* and *Gay-Lussac's* law does not apply to saturated vapours, nor even to vapours slightly superheated. It is only for a very high degree of superheating that the coefficient of expansion, very variable, approximates to the value (0.00367) relative to gases (experiments of *Siemens*, *Fairbairn* and *Tate*), and the value $k = 1.408$ cannot be applied to vapours.

368. *Expression of the work of the adiabatic or theoretical expansion.* The exact expression of this work is at once written down. The vapour having, during the expansion, neither taken nor ceded any heat to the sides, the heat transformed into work is the difference between the quantities contained in the mixture, at the beginning and at the end of the expansion.

t and t_0 being the initial and final temperatures; ρ and ρ_1, the corresponding values of the internal latent heat of the vapour; x_1 the quantity of vapour contained originally in the unit of weight of the mixture, or what is often called the *standard* of the mixture, and x_2 this standard at the end of the expansion; P = the weight of the mixture contained in the cylinder, we have :

Heat of the mixture at the beginning of the expansion : $P(q + \rho x_1)$,

do. end do. $P(q_1 + \rho_1 x_2)$.

Then : heat converted into work : $P(q - q_1 + \rho x_1 - \rho_1 x_2)$,

and the work of the expansion is : $\frac{P}{A}(q - q_1 + \rho x_1 - \rho_1 x_2)$.

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one, much too feeble, obtained by means of chimneys in iron-plate the height of which reaches 66 feet, a dimension which there would, moreover, be no advantage in raising.

The suction-fan seems to him also much more economical than jets of steam from the boiler, a method worked out at *Indret*.

(*) *The steam-engine*, 8th edition, p. 249. 1 vol. 12mo. London, Griffin and Co. 1876.

x_1 standard at the beginning, is given. If the steam is dry, then $x_1 = 1$. x_2 is deduced from *Clausius's* relation, already quoted (114), and to which we are about to return (360).

2nd. *Approximate expression.* It has been endeavoured to express this work, as has been done for the adiabatic expansion of gases, in function of the pressures and volumes, but it is then only a simple empirical formula in question, in which the exponent k is determined in such a way as to work in the formula with the results of observation.

p_0, v_0, relating to the beginning of the expansion, p, v, at any moment of that period, we have for *air* (113):

$$(a) \qquad pv^k = p_0 v_0^k,$$

whence

$$\int_{v_0}^{v} p\,dv = p_0^k \int_{v_0}^{v} \frac{dv}{v} = \frac{p_0 v_0^k}{k-1}\left(\frac{1}{v_0^{k-1}} - \frac{1}{v^{k-1}}\right)$$

$$= \frac{p_0 v_0}{k-1}\left(1 - \frac{v_0^{k-1}}{v^{k-1}}\right) = \frac{p_0 v_0}{k-1}\left[1 - \left(\frac{p}{p_0}\right)^{\frac{k-1}{k}}\right],$$

for (a) gives

$$\frac{v_0}{v} = \left(\frac{p}{p_0}\right)^{\frac{1}{k}}, \text{ whence } \left(\frac{v^0}{v}\right)^{\frac{k-1}{k}} = \left(\frac{p}{p_0}^{\frac{k-1}{k}}\right).$$

p, being the pressure at the end of the expansion, the total work of the expansion, $\mathfrak{T}$, is

$$\mathfrak{T} = \frac{p_0 v_0}{k-1}\left[1 - \left(\frac{p_1}{p_0}\right)^{\frac{k-1}{k}}\right]$$

Value to be attributed to k for steam. M. *Grashof* admits $k = 1.14$, but supposing exactly at the point of saturation, without liquid water at the commencement of the expansion (*); and *Rankine* $k = 1.3$ (**).

According to M. *Zeuner* (***), the mean value $k = 1.135$ is applicable to all cases which are presented in steam-engines, but only for steam saturated and dry at the beginning of the expansion (****). This value diminishes and approximates to 1, if there is liquid water, and the more so the more water there is. x_1 being always the quantity of vapour contained in the unit of weight of the mixture, M. *Zeuner* gives (*****) the empirical formula $k = 1.035 + 0.1\,x_1$ (for $x_1 = 1$, $k = 1.135$) as applicable between $x_1 = 1$ (dry steam) and $x_1 = 0.7$ (30 per cent of liquid water, $k = 1.105$).

(*) *Zeuner. Théorie mécanique*, page 329.
(**) *Steam-engine*, p. 320.
(***) *Théorie mécanique*, p. 334.
(****) *Théorie mécanique*, p. 334.
(*****) *Théorie mécanique*, p. 335.

The more the steam is charged with water, the nearer k approximates to 1; the more in that case the adiabatic curve $pv^k = p'v'^k$ approximates to the equilateral hyperbola $pv = p'v'$ of *Mariotte's* law.

This law, true for perfect gases expanding at *constant* temperature, is the less inexact for the adiabatic expansion of steam, the greater the proportion of water.

Thus is explained a fact to which we shall soon return and which it is desirable to mention at this time, because it was supposed to contain an argument against the mechanical theory of heat. In the diagrams taken by means of the indicator, particularly from locomotives, especially at low speeds, it is remarked that the part of the curve which corresponds to the expansion deviates little from an arc of an equilateral hyperbola; whence it has been concluded that steam expands according to *Mariotte's* law, at constant temperature at variance with the principles of the theory.

It is on the contrary a confirmation of those principles, which would result from the observation in question. It is not dry steam which expands; it is always, in locomotives especially, mixed at the commencement of the expansion, with a considerable proportion of water. k thus approximates to unity, and the real curve to the equilateral hyperbola.

Other phenomena intervene, and superpose themselves, so to say, during the real expansion, as we shall see. But let us continue the investigation of the theoretical cycle, without prematurely confusing it with the facts which take place in actual engines.

369. *Condensation in the adiabatic expansion.* Here comes in the fact, or more correctly speaking, the group of facts of which we have already spoken (351), a very interesting group, not, as we have stated, for practice, for in engines there is neither *dry saturated steam*, *adiabatic* expansion, nor impermeable sides to deal with, but by the confirmation which results from it for the theory.

Clausius and *Rankine* established nearly at the same time (in 1849), this principle :

When dry saturated steam expands or contracts without addition or subtraction of heat, there is in general *condensation* in the first case, and, on the contrary, *superheating* in the second.

But although these two justly celebrated names are ordinarily associated, when it is a question of the condensation of dry steam during *adiabatic* expansion, it would seem that their labours on this point, are of a different order and importance.

According to M. *Verdet* (*), " Rankine had been led to ascertain the fact in endeavouring to account to himself for the well known fact of the accumulation of liquid, which is always produced in the cylinder of an engine, when it is not surrounded with a steam-jacket. "

If this is really so, Rankine must have drawn a true conclusion from a fact in no way including it, which indeed had no relation with it. He thus extended to the adiabatic expansion of dry steam, more by good luck than by judgment, a fact observed under quite other conditions, and due to quite another cause. However it may be as regards this, we shall see directly that the eminent professor of Glasgow College did not escape from the error into which the two French scientists fell (perhaps from having gone too much by him); and that " the accumulation of water in the cylinder is not due to condensation during expansion. "

But, at any rate Rankine took care not to see in the precipitation of water during the expansion, the great fact that the two authors believed to have discovered therein... at first. And he brings out the consecutive drawbacks which it involves (**).

Clausius's relation, which expresses the law in question, is (114, p.) :

$$x_2 = \frac{T_2}{r_2}\left(\frac{x_1 r_1}{T_1} + c \text{ log. nat. } \frac{T_1}{T_2}\right);$$

it may be put under other forms, but this one is sufficient.

Let us recall the signification of this expression :

Let there be 2 lbs of water (liquid) at t_1^0 under the pressure p_1: let us evaporate a portion of that water, under the same pressure and at the same temperature; let us leave it to expand in an impermeable envelop to the pressure p_2 and temperature $t_2 < t_1$, seeing that there is a production of work without addition of heat; x_2 being the quantity of steam at the end of the expansion, r_1 the quantity of heat necessary to evaporate 2 lbs of liquid water at t_1^0, r_2 the quantity of heat necessary to evaporate 1 lb of liquid water at t_2, c the specific heat of water, T_1 and T_2, $460 + t_1$ and $460 + t_2$, the sign of the difference $x_1 + x^2$ shows the direction of the effect produced.

In general, with steam originally dry and saturated, that is to say for $x_1 = 1$, this direction depends on the temperature t_1. So long as it does not exceed for steam, about 970°, $x_1 - x_2$ is positive, or $x_2 < 1$; it is thus a condensation which takes place by the adiabatic expansion; beyond 970°,

(*) *Théorie mécanique*, p. 251.

(**) *Steam-engine*, etc., pp. 395 and 396.

$x_1 - x_2$ is negative or $x_2 > 1$, an impossible value, indicating that there is a *tendency* to the formation of fresh steam, and, consequently, in reality, *superheating*.

Conversely, by *adiabatic* compression, it is superheating which takes place, theoretically, below 970°, and condensation above.

It is the contrary with the vapour of ether: to the expansion a superheating takes place; to the compression a condensation; but what was first considered to be an anomaly arises simply from the fact that the temperature of the *inversion of the effects* is very low: — 207° instead of 970° for water.

For this temperature of inversion itself, the effect is *nil*: $x_2 = x_1$.

370. *Experimental verification.* M. *Hirn* has verified by experiment the correctness of the deductions of theory. He introduced saturated steam *very* dry, at a pressure above that of the atmosphere, into a copper cylinder closed at the two ends by glass covers. The cylinder was thus perfectly transparent; but as soon as, by opening a cock, steam was allowed to escape, there was a rapid expansion: the steam partly condensed, forming an opaque cloud. The theoretical conditions were in that case strictly fulfilled: steam strictly *saturated*, — sides perfectly exempt from deposited water (steam had been circulated round them in order to keep them quite hot), — very prompt expansion, — so that the action of the sides was nothing, or nearly so.

M. *Hirn* verified equally the partial condensation of the vapour of ether by the reverse action, that is to say by compression. The cock was replaced by a piston; as soon as it was pushed along the cylinder, the cloud appeared.

The phenomenon of the condensation took place also (as M. *Hirn* remarks) in boilers in a state of ebullition, the pressure increasing from the level of the liquid to the bottom. We shall not dwell on this point, the difference of pressure being of importance only in the great vertical boilers heated by the flame from puddling and reheating furnaces.

When the boiler supplies an engine, it is by a series of jerking emissions, during which the pressure lowers to rise again in the intervals. There are thus intervals of expansion and compression. During the first, the water condenses, and is carried over into the cylinders.

371. *Errors caused by the false interpretation of the preceding effects.* That strictly saturated steam — expanding in producing work and consequently losing heat, — and supposed to receive none to make up for that loss, — has no longer enough to maintain itself at the point of saturation, and partly condenses, — there is certainly nothing but what is quite simple from the

point of view of thermo-dynamics, and that could not be foreseen. What is really remarkable, is the *measure* of the phenomenon, deduced from the theory by M. *Clausius :* But as in the old order of ideas, one was accustomed to consider, on the contrary, as a consequence of the expansion, a fresh evaporation for moist steam (and that is what in effect does take place, but under the action of the sides) and superheating in the case of dry steam, the fact in itself, established by *Clausius* and confirmed by M. *Hirn's* experiment, has caused a sort of astonishment. This fact was started from, and it contains nothing essential in itself — which may be produced in engines, but which, in reality, is therein almost always replaced by the precisely contrary fact, to make of it, for what purpose it is difficult to say, — the basis of a sort of sketch of a brief theory of the steam-engine; and this unfortunate generalization of a fact the bearing of which is purely theoretical, has brought confusion into the ideas of those who have neither the time nor the means to go deeply into things.

Under the sway of views too exclusively theoretical, distinguished physicists have contributed to that confusion, and the clearest heads, those who are justly looked on as authorities in the knowledge of engines, have not always escaped from the influence of these views. We have already quoted M. *Verdet* and M. *Briot*. It will not be without benefit to complete the extracts made above from these two authors.

" There can be brought ", says the first (*), " to the support of this conclusion (a condensation, in the cylinder, of the steam originally saturated), a daily observation of industrial practice. Every one knows the injurious accumulation of liquid which takes place in the cylinder of an engine, when it is not surrounded by a steam-jacket. One of the most eminent engineers in Great Britain, M. *Rankine*, has ascertained that the origin of that deposit is the condensation which accompanies the expansion and not as was believed, the accidental carrying over of water from the boilers. "

We have already said (369) that the origin of this *deposit* is not the *condensation during the expansion*, since that there is none; seeing that instead of increasing during the expansion, the quantity of water diminishes; it is the condensation during the *admission*.

" Let us consider, for example, says M. *Briot* in his turn (**), a high-pressure engine the boiler of which is at 305°, and the condenser at 100°, and let us suppose the expansion finished, that is to say that the steam, after the expansion, has a tension equal to the maximum tension of the steam at 100°; the quantity of heat necessary to bring 2 lbs of

(*) Vol. I, p, LVII.

(**) *Théorie mécanique*, pp. 104 and 105.

water at 32° into the state of steam is approximately 1175 units of heat. But as the feed-water is at 100°, the expense of heat for each pound of steam is 1103 units of heat. If the steam did not undergo any partial condensation during the expansion, and arrived in the condenser in the state of dry saturated steam at 100°, condensing at that temperature, it would give up 1042 units of heat. The difference, or 61 units, would be converted into work; the economical coefficient would be only $\frac{61}{1103}$, about $\frac{1}{18}$ th.

" Let us imagine at the same time, that the engine is working between the same limits of temperature 406° and 100°, according to a *Carnot's* cycle; the economical coefficient will be

$$\frac{T-T'}{T} = \frac{206}{765}, = \text{about } \frac{1}{4} \text{ th.}$$

Thus the economical coefficient calculated according to the *old theory* is four times too low. *This fully shows that a part of the steam is condensed during the expansion*, and that the heat disengaged by that partial condensation has been converted into work.

To the numerical value given by M. *Regnault*, M. *Verdet* opposed, at any rate a real yield, that of the engines on which M. *Hirn* experimented.

But to what he calls the yield according to the old theory (?) M. *Briot* opposes the theoretical limit yield, that of Carnot's cycle; and because that limit is four times more than the figure corresponding to M. *Regnault's* hypothesis, he concludes therefrom that it is the latter which is four times too low! But if this figure, which has, however, as we have seen, no other value than that of a particular example, may be and often is too small, the other is *always* too great, and often much too great.

And from the fact that there is, — no!... from the fact that there would be a condensation, during the expansion, in *Carnot's* cycle, if it could be realized, — to conclude that this condensation equally takes place in actual engines, and tha then the whole thing is done, is a remarkable error, which it would have been easy to avoid. Under the influence of a theoretical idea, the two authors continued, wishing to enter into practice, to make abstraction of the action of the sides, an action which so profoundly modifies the effects.

" We have admitted, says M. *Combes* himself (*), that steam in a state of saturation and *entirely dry* expands without addition or subtraction of heat, and we have shown that the expansion is always accompanied by partial liquefaction. *It is nearly so that things should take place in ordinary steam-engines.* It is sarcely possible, in effect, to communicate heat to the steam in the act of expansion, *which takes place too rapidly for the steam to reheat itself appreciably through its whole mass at the expense of the sides of the cylinder, which would be at a higher temperature.*

(*) *Exposé des principes*, p. 146.

Experience gives a complete contradiction to the lines of this passage which are italicized.

While admitting, wrongly, that the theoretical conditions of the adiabatic expansion are in general fulfilled in " ordinary engines ", M. *Combes* took care to add that this may possibly not be the case.

Only, he misunderstood the almost general nature of the effect, precisely the reverse of the theoretical effect, because he only saw the cause (after having however formerly observed where it exists [385]) in the water mixed with the steam and carried over by it, while that cause dwells mainly in the water which is precipitated during admission, on the cooled sides of the cylinder.

With this reservation, the two following passages merit reproducing :

" We (*) have shown that steam at saturation and *perfectly dry* partially liquifies, or passes into the state of superheated steam, according as its volume is augmented or diminished, without addition or subtraction of heat, and exerting at each moment on the sides of the vessel of varying capacity which incloses it, a pressure equal to the elastic force which it possessed in the statical state with regard to its actual density and temperature. Precisely contrary effects may be produced when the steam, instead of being dry, is mixed with a certain quantity of water, at the same temperature as itself. "

Thus at the temperature of 302° for example, it is a *condensation* which would take place by *adiabatic* expansion, so long as the proportion of water were inferior to 0.461, and an evaporation when that proportion became exceeded. For this strict ratio, an infinitely small expansion or contraction, without addition or subtraction of heat, would produce no change of state.

The more elevated the temperature, the less the proportion of water to which the inversion of effect corresponds. Thus at 400°, it falls to 0.396.

' It is extremely rare, " adds (**) M. *Combes*, " that, in theusual engines, the quantity of water carried over by the steam coming from the generator reaches the proportion necessary to the expansion, without addition or subtraction of heat, does not give rise o the precipitation of a part of the steam instead of producing, as is generally believed, the partial or total evaporation of the water carried over. The quantity of liquid *water increases thus during the expansion*, and this circumstance has a favourable influence on the useful effect of the engine, seeing that it augments the quantity of heat converted into mechanical work. "

It is rare, in effect, that the proportion of water *carried over*, at which the condensation commences to give place *theoretically* to evaporation, is

(*) *Exposé des principes*, p. 144.
(**) *Ibid.*, p. 157.

reached, even in locomotives. Which does not prevent the second effect from being constantly produced, or the quantity of liquid water from diminishing during the *expansion*, contrary to *Combes's* statement. It is that the question is very far from being only, of water mixed with the steam; and that the sides lined with water during admission, are very far from acting as theory supposes.

As to the increase in the quantity of *heat converted into mechanical work* by this condensed water, by what inadvertence did the eminent engineer forget the objectionable effects of the ulterior evaporation of this same water during the exhaust (378)?

We have complained of Mr *Rankine* having been perhaps the first to draw, from the condensation during adiabatic expansion, consequences quite false as regards steam-engines; let us justify this assertion. The great and legitimate authority of the eminent professor, as scholar and specialist, does not permit of an error being passed over, which has, probably, led more than one engineer astray.

One short quotation will be sufficient. We read in *the Steam-engine* (*) (pages 395 and 396):

" The conclusion theoretically demonstrated in article 283, that when steam or other " saturated vapour, in expanding performs work by driving a piston, and receives no " heat from without during that expansion, a portion of it must be liquefied, *is con-* " *firmed by experience in actual steam-engines; for it has been ascertained that the* " *greater part of the liquid water which collects in unjacketed cylinders, and which* " *was once supposed to be wholly carried over in the liquid state from boiler* (a pheno- " menon called : priming) *is produced by liquefaction of part of the steam during its* " *expansion...* "

Misled also by an observation made under theoretical conditions, Mr *Rankine* thus misunderstood the origin of the water deposited, often in such abundance (374) in unjacketed cylinders. He attributes it to the expansion, which produces on the contrary almost always an evaporation, instead of seeing the cause of the phenomenon, as well as that of the evaporation, where they really are, that is to say in the action of the sides during admission at first, and afterwards during the expansion.

§ V. — Divergences between *Carnot's* cycle and actual engines.

372. In actual engines, the steam coming from the boiler is not dry, but

(*) 8th edition, 1876.

more or less wet. The sides of the cylinder are not neuter. Clothed with water during admission (especially in condensing-engines where they are cooled more) they constitute veritable *sources of heat*, and play instead of the passive part admitted by theory, a very important and very complex one.

Of what good then, it may be said, is this theoretical conception?

It is most essential, in order to establish a theory, to deal with clearly defined conditions, more or less abstract and simple, even if in so doing, reality is greatly departed from. It is thus that general laws can be obtained true at the limit. Thus we arrive at the expression so simple of *Carnot's* cycle, a theoretical expression, but one the importance of which for practice we have no need to urge.

We shall now, as we did for *Carnot's* cycle, follow rapidly the various phases which take place in locomotives, starting (without returning, of course, to the details) from the system of distribution which has become classic for those engines, and which, in effect by the simplicity of the means as by the satisfactory utilization of the steam, is so suitable to that class of engine (*).

Let us note first of all, an essential point.

373. *Choice of the intermediate body.* Between the same limits of temperature of a *Carnot's* cycle, the ratio of the heat converted into work, to the heat furnished by the hot source, is independent of the nature of the intermediate body. Theoretically, the choice of this body is quite indifferent.

It is quite otherwise in practice. The nature of the body influences the consequences of the *divergences* from the real cycle, relatively to the theoretical cycle of maximum yield; it brings in actions and effects which theory takes no notice of, but which the practical man has to take into great account; it influences the conditions of volume and weight of an engine of given power, and the possible amount of the fall $T - T'$.

If it be desired, for example, to compare air and steam as vehicles of heat. The air, and this is its seductive property at first sight, may be carried to a high temperature without the result as with steam at satu-

(*) Locomotives had remained hitherto in the rear of the great progress introduced first into stationary engines (Woolf's), and more recently into steamboats (compound engines). M. *A. Mallet* had lately the happy idea of extending the principle to the locomotive, keeping its general arrangement, that is to say making the two pistons of unequal diameters act on two cranks at right angles. His want of symmetry does not appear incompatible with steady running, and a notable economy of fuel is at any rate very probable.

ration, an excessive pressure; but the air has, it may be said, the reverse fault: at constant volume its pressure increases too slowly with the temperature; in order to obtain, without exaggeration of the volume of the cylinder, a *reasonable amount* of work, per stroke of the piston, this temperature must be very elevated, 500° at 600° at least. The yield increases accordingly; but in this state, the air acts on the grease and oil not only as a highly superheated steam, but in a much more detrimental way; it spoils them and prevents their fulfilling their function, which the very elevation of temperature would render more necessary than ever. The volume of the apparatus excludes also the application of the principle to powerful engines, for which it would become enormous.

The air possesses another property which appears, in the eyes of persons unacquainted with the fundamental principles of the theory, to dispose of the question decidedly in its favour. By dilating the air, a perfect gas at least, at a constant temperature, the internal work is *nil*. All the heat supplied is thus employed in producing external work, seeing that there is neither elevation of temperature, nor internal latent heat. It would therefore seem that, on that account only, air should be much more economical than water. But what does it matter, theoretically, that the internal work of the body has absorbed heat, seeing that its evolution is a closed cycle, and that, at the beginning of each period, it is found again in the same molecular state?

Without doubt, in the case of water, a great deal of heat must be expended in internal work. But it is restored in part, by the expansion, while with air, the work furnished by the expansion is absorbed entirely by the adiabatic compression, so that all the gain is the excess of the *positive* work corresponding to the first isothermal curve, over the *negative* work corresponding to the second.

In fact, the yield of the air-engine might perhaps be augmented, and attain even the theoretical yield, by having recourse to the contrivance pointed out by *Stirling*, then by *Ericsson*, that is to say to the *regenerators* of heat; but, hitherto, practice has been unable to gain anything by this idea. And were it successful in application, this advantage could not compensate for the disadvantages of air, unless at the most, for engines of small power.

Compressed air. If it be desired, instead of accumulating and keeping work under the form of heat in the water of a generator, to make use of air in order to accumulate directly therein mechanical work by compression, it is well known what difficulty arises, a difficulty the reverse of that we have just referred to. It is impossible to apply the expansion to

any great extent, the fall of temperature which results therefrom congealing oil and even water; so that while greatly limiting the expansion, it is necessary to bring in a source of heat, that is to say, to mix in some measure the two systems.

Several efforts have been made to apply compressed air to locomotives, and this problem long occupied M. *Sommeiller*. It is quite natural in effect to turn to air, when the use of steam is impossible. At the present time, locomotives with compressed air are working the internal traffic in the *Saint-Gothard* tunnel.

But, in spite of the remarkable application made by M. *Mékarski* to tram ways, it seems difficult for compressed air to carry the day, even on this restricted ground, unless the prohibition of steam (which would only be warranted in rare cases) leaves the field clear.

Let us now then return to the phases which succeed each other in the real engine.

374. I. *Admission*. It presents no notable divergence relatively to the corresponding phase (first isothermal curve) of *Carnot's* cycle. Two facts, of unequal importance however, ought nevertheless to be pointed out : the fall of pressure, and the precipitation of water on the sides of the cylinder.

1st. *Fall of pressure in the cylinders*. The steam rushes eddying into the cylinders, on account of the abrupt change of section; its velocity cannot completely be extinguished during the short interval of admission, and the result is that the pressure exerted on the piston is less than the statical pressure in the boiler (or, more exactly, the valve-chest; but locomotives run always with the regulator sufficiently open for the difference to be very small.)

To this fall of pressure, due to what is called the *wire-drawing* of the steam, corresponds a fall of temperature, and consequently a loss of yield. If the steam were dry, or nearly so, the fall of temperature might be less than that which would be deduced from the fall of pressure, as the steam might then be superheated. Besides, the vis viva, in extinguishing itself during the expansion, is converted into heat, so that the second period benefits thus by a portion of the loss undergone by the first.

The depression varies, from one engine to another, at equal velocity, with the type and the details of distribution, the admission lead among others; and for a given engine, it depends on several elements, notably the mean velocity of the piston, and the degree of admission.

It has been sought to represent their influence by empirical formulæ.

One of them is in use in the locomotive drawing-offices, where it is known by the name of : *Orleans reduction formula.* I do not reproduce it, M. *Forquenot* having informed me that the experiments from which it was deduced, were affected by some errors. A rectified formula is being drawn up.

The depression increases with the mean speed of the piston; it becomes nothing for low speeds, for example, for certain engines, 3.28 feet per second.

The influence of the degree of admission is marked, as is easily imagined, but its variations do not always act in the direction which would be supposed at first sight.

We have seen (175, *numerical examples*) to what a degree the throttling of the ports reaches, by small admissions. Two engines having, for different admissions, the same maximum opening of the ports, it is to the smallest admission that the least depression would correspond, if the admission lead and the compression had the greatest values for that admission.

For the same engine, the depression often diminishes also with the admission, and that within very wide limits, at least for certain types, a restriction always necessary in such matters.

Let us quote some facts observed by M. *Bauschinger*, remarking that the figures given, taking the pressure in the boiler as unity, express, not the *mean* pressure, but the maximum pressure during admission.

1st. *Ampfing engine.* As long as the admission does not exceed 0.5 and the mean speed of the piston 8.20 feet, the maximum pressure in the cylinder during admission rises to 0.98 and reaches even 1.00 (*).

2nd. For admissions greater than 0.5, the maximum pressure did not exceed 0.90, even when the mean speed of the piston was 4.92 feet at most.

3rd. An engine (*Lichtenfels*) gave, for a piston-speed of 12.47 feet, a maximum pressure of 0.98.

These facts are the expression of complex influences. The engines in this case had *Stephenson's* link with direct rods, a system in which, as we know, the leads increase when the admission decreases. The more the ports are throttled, the more the admission-lead itself increases. The first fact tends to aggravate the fall of pressure, the second to reduce it; the increase of the admission advance, very favourable to the prompt establishment of the pressure in the cylinder, more than compensates for the reduction of opening.

From one engine to another, and for the same admission, the influence

(*) *Indicator-Versuche*, p. 31.

of the speed on the depression is less in proportion as the advance is greater. It is this which explains the remarkable result given by the *Lichtenfels* engine.

Prolonged compression, which is inseparable from a large amount of expansion, or of a small admission, tends also, on its part, to raise the temperature and the pressure at the beginning of the admission.

In the discussion of the diagrams which he took, it is principally to the pressure in the valve-box (a pressure often very different from that of the boiler, on account of the small amount by which the regulator is then opened) that M. *V. Grimburg* referred the pressure in the cylinder during admission; and, instead of the maximum value, it is the mean value which he has taken, which renders the ratio more significant. We shall limit ourselves to taking the following table from him, in which the pressure during admission is expressed by taking the pressure *in the boiler* as unity, and which brings out for one speed (about 19 miles an hour), the influence exerted by the depression on the length of admission; it is expressed in hundredths of the stroke.

ADMISSION in hundredths of the stroke.	MEAN PRESSURE in the cylinder during admission, the pressure in the boiler being 1.
76	0.39
64	0.57
49	0.60
35	0.65
31	0.69

The first consequence is then the same as that of M. *Bauschinger's* : — The fall of a pressure diminishes with the admission through a great range of the scale (the limit is not reached for the admission of 31 per cent) in spite of the decreasing section of the *maximum* opening of the port, which at this degree, is only $\frac{1}{70}$ of the section of the piston. The interest presented by the numbers in the second column consists in the law which they follow. As to the smallness of the starting-point, 0.39, it is simply the consequence of the small opening of the regulator which of course remained constant.

The *Leopoldstadt* had, like the engines operated on by M. *Bauschinger*, *Stephenson's* link and direct rods (*). The figures of the two series are at

(*) Out of the eight studied by M. *Bauschinger*, four were with *Stephenson's*, and four with *Meyer's* link. His experiments have fully established the economical superiority of the first type over the second, for which the expenditure of steam per indicated horse and per hour, is always far greater, as long as the expansion is not pushed very far.

the same time quite comparable, seeing that the first gives the maximum pressure and the second the mean pressure. Now, the fall or the expansion during admission is often very appreciable, as is indicated by the line of admission on several diagrams.

With *Gooch's* valve-motion, with constant advance, the depression from the boiler to the cylinder diminishes when the admission increases.

Example : M. *Polonceau's* experiments, engine 736 :

ADMISSION in hundredths.	PRESSURE IN THE CYLINDER, the pressure in the boiler being 1.
22	0.83
37	0.89
44	0.91

Sometimes there occurs something like a trace of the reverse fact, for example, in engine 268 :

ADMISSION in hundredths.	PRESSURE IN THE CYLINDER, the pressure in the boiler being 1.
18	0.92
24	0.91
53	0.90

but a decrease so little marked is very nearly equivalent to equality.

2nd. *Condensation during admission.* The cylinders constantly cooled on the outside (more ore less according to their position, the speed, and the atmospheric conditions), are so on the inside during the exhaust, that is to say during the communication with steam at 212° or nearly. The conditions under which the fourth period is effected (compression, 380) modify at the same time more or less the temperature of the cylinder, at the moment of the commencement of the admission. If they are such that this temperature is very inferior to that of the steam, the latter, even dry, is partly condensed. In condensing-engines, where the cooling of the cylinder is more marked and the compression very slight or nothing, this precipitation may amount, as has been ascertained by MM. *Hirn* and *Hallauer, to* 60 *per cent of the steam admitted.* In locomotives, the condensation properly so termed by the action of the less cooled sides, is less; but, as the steam arrives in those, much more charged with water, the quantity of water deposited during admission is equally very considerable.

It is thus during admission that condensation is *always* produced.

375. II. *Expansion.* Conversely, it is not a *condensation* which is produced during this period, but an *evaporation*, often considerable.

Very generally, in effect, the quantity of *steam augments*, instead of *diminishing*, as is wrongly asserted. Let us make known the experiments which establish this fact.

Effect of leaks. Verification. We shall first put aside an accidental cause which might produce this inequality, but which might just as easily produce a reverse one, that is to say a diminution of the steam contained in the cylinder at the end of the expansion; viz. a leak under the slide.

If it is the edge A (Pl. XVII, *fig.* 5) which is not tight, it allows the steam to filter in, from the box into the cylinder; if it is the edge B, it lets steam filter out of the cylinder into the exhaust.

We must thus, above all, in order to analyze what takes place during the expansion, be perfectly sure that there are no leaks either in one way or the other.

This is what can be easily ascertained.

The slide being placed symmetrically with reference to the ports, and the blow-off cocks open, the regulator is opened.

If both the cocks blow off, there is a leak on each side of the slide, or else one in the slide and one in the piston. If neither of the cocks blows off, the slide is tight (that does not prove that the piston is, but it is sufficient to make sure that the slide admitting on one side, the cock of the other side does not blow off.)

Although sufficient in general, the verification made in the mean position of the slide, is not always perfectly conclusive for large admissions.

Locomotives run ordinarily with very reduced admission and slide travel. The port-faces become thus worn chiefly in the central portion, which takes a slightly concave form upwards. Tight in its mean position, the slide cannot be so when, towards the extreme positions of its full travel, it bears, by one edge, on a portion of the port-face less worn; but the only point that concerns us here, is that it may be tight during the passage of the lap over the admitting-port, that is to say in its mean positions.

376. M. *Bauschinger's experiments.* Let us pass on, that being disposed of, to M. *Bauschinger's* experiments (*), and to the main fact which they establish.

After taking several hundreds of diagrams, at different degrees of admis-

(*) *Indicator-Versuche an Locomotiven.*

sion, off eight locomotives of the Bavarian railway, M. *Bauschinger* traced for the same notches the theoretical expansion-curves corresponding to the various hypotheses; namely :

1st, Temperature constant; *Royle's* law;

2nd, Neither addition nor subtraction of heat; *adiabatic* expansion, in three cases : *a* steam, at the beginning saturated but dry; *b* steam containing at the beginning 40 per cent of water; *c* steam containing at the beginning 70 per cent of water;

3rd, *Rankine's* law, founded on the hypothesis (more or less applicable to jacketed cylinders) that the steam takes enough heat from the sides to keep it dry. M. *Zeuner's* tables for dry saturated steam give the necessary elements for the trace of the curve;

4th, MM. de *Pambour* and *Redtenbacher's* hypothesis, the expression of which is, analytically, $p = \frac{v}{v_0}(0.284 + p_0) - 0.284$, p and p_0 being in atmospheres.

The real curve is always notably below all the others, as the two diagrams show (*figs.* 9 and 10, Pl. XVIII) taken from M. *Bauschinger* and taken off the same engine (*Ampfing*), the first with an admission of 0.14, the second with an admission of 0.33; that which approaches the nearest is always the equilateral hyperbola (*). The divergence varies not only, from one engine to another, but also in the same engine from one side to the other, and for the same cylinder, from one stroke to the other.

Thus, the real curve is always less high for the return than for the orward stroke, which arises from the more powerful cooling action on the front end of the cylinder, more exposed to the wind than the hinder end. We observe also on the curves a clearly marked influence of the atmospheric influences, which were noted with care at each experiment.

These external influences and those of the frequent variations of admission and speed, which characterize the running of locomotives, introduce into the run of the real curves, elements of irregularity from which stationary engines are exempt.

How to explain this sustained elevation of the real curve, even above that of Mariotte's law, which supposes the temperature constant? What is the source of heat, which thus maintains the tension?

This source can only be the sides of the cylinder, and of the piston; but how during the short interval of the fraction of the stroke which corresponds to the expansion, can they cede directly to the steam, the quantity of heat necessary?

(*) In figure 9, the *adiabatic curve* for steam with 60 per cent of water, is a little above the equilateral hyperbola.

What maintains the pressure so elevated, is not the heat furnished by the sides, during a part of the expansion, to a *constant quantity* of steam (and which would even diminish, as we have seen, if the steam were dry and the action of the sides nothing); it is the *production of a fresh quantity of steam, formed by the water precipitated on the sides during admission* (374). Nothing is easier than to follow the connection of the facts. The steam already moist, laves the cooled sides, it heats them in partly condensing, the admission-port closes; the expansion commences, the temperature of the steam, which expands producing external work, rapidly lowers, and reaches that of the sides; then the water which clothes them evaporates and keeps up the pressure.

The proportion of water contained in the cylinder at the beginning of the expansion may be deduced approximatively, as was done by M. *Bauschinger*, from the form of the portion of the diagram which corresponds to the expansion. Let us take for example the diagram *fig. g*, Pl. XVIII (*).

If the steam (at the absolute pressure of 7 ats in the boiler) were saturated, but dry at the beginning of the expansion, at *a*, it could only have, at *c*, the pressure *c p* of the diagram, by reason of superheating due to the heat ceded by the sides. But this superheating would have to reach quite impossible proportions. In the case in question, in order that the superheated steam, supposed to follow in its expansion the law of the perfect gases, should have, at *c*, the pressure indicated, its temperature ought to rise to about 480°.

This temperature is less if we suppose the steam to be mixed, at the beginning of the expansion, with a certain proportion of water, and it lowers the more, the greater this proportion. With 20 per cent of water the intervention of the superheating would be still necessary in order that the pressure at *d* should be equal to *d p'*; but the temperature would only then be 420°, the evaporation of the 20 per cent of water by the heat taken from the sides (and consequently from the steam during admission) keeping the steam saturated during a portion of the expansion, up to *b*. With 40 per cent of water, the final pressure *e p''* is reached without the steam ceasing to be saturated.

So considerable a proportion is not always necessary, by a long way; thus, in the case represented by the diagram (*fig.* 10) (pressure in the boiler 8 ats.), 12 per cent is sufficient to maintain up to the end of the expansion, at *e*, the real pressure *e p*, without superheating; while with steam dry at

(*) Fig. 1 of M. *Bauschinger's* Pl. VI.

the beginning, the temperature would have already risen at b, as high as at d in the preceding case, that is to say 420 :

The quantity of water in question here is the total amount of that which the cylinder contains, at the beginning of the expansion; it includes both the water carried over by the steam, and that condensed by the sides during the admission.

If, besides, the considerations which precede prove that this *total water* is very variable, and often very considerable, we can scarcely rely on the numerical values to which they lead, the assimilation of steam, even superheated, to perfect gases being by no means correct.

But M. *Zeuner's* tables allow the quantity of water *produced during the expansion* to be deduced pretty accurately from the examination of the diagram.

The beginning a of the expansion, and that e of the exhaust may be taken from the diagrams with a good deal of precision (*). The tables give the specific weights of the saturated dry steam at the pressures $a\,p$, and $e\,p''$, and, consequently, the absolute weights of steam contained respectively in the volumes known, limited by the pistons at p, and p'.

If the steam were really dry at p, the second weight would be less than the first, — it would be the effect of a condensation, — but it could not be greater, seeing that there would be no water to furnish fresh steam.

Now, there is always found, for the second weight, *a greater value than for the first.*

The difference is the quantity of steam formed during the expansion.

We get however only a minimum of the quantity of water contained in the cylinder. For this to be the *total weight*, this water would have to be entirely evaporated at the end of the expansion, and the steam dry.

In all M. *Bauschinger's* experiments, there was evaporation during the expansion. Referred to the total quantity of wet steam expended, this water evaporated varied between 0.10 and 0.41 (**).

As we pointed out before, the conversion of the heat of the *vis viva* which the steam possesses when the admission ceases, contributes also to the raising of the expansion-curve, thus partly compensating for the depression of the line of the admission.

What becomes, in the face of these results, of the explanation given by

(*) It is the same at the beginning of the compression; as to that of the introduction, the diagram does not give it clearly. It is however, more correct to take off those points directly, as M. *Grinburg* did, on the engine moved by hand.

(**) See *Indicator-Versuche*, table VI, p. 115 and following.

MM. *Verdet* and *Briot*, of the *secret, of « the source of the power of steam-engines »?*

At the same time, these facts were not even necessary to cause the collapse of the pretended explanation which, we have seen (and we shall see again on the subject of jacketing), does not stand one moment's examination.

377. M. *V. Grimburg's experiments.* M. *V. Grimburg's* experiments present, in their general results, less uniformity than M. *Bauschinger's*. In the latter, the increase in the quantity of steam during the expansion was the constant fact. In M. *Grimburg's*, the reverse, that is to say a condensation was often recorded. This, as we have already said, is nothing but what is quite natural. The direction of the phenomena of detail varies according to circumstances; and if this condensation during the expansion, of which it has been desired to make a necessary law, of main importance, is in reality a rare fact, it may be produced in some cases. Thus one of M. *V. Grimburg's* experiments gives a condensation which reaches 0.30, by the side of others which give an equal *evaporation*, and that under equivalent conditions of yield; it is seen more clearly by that to what we are exposed by an adherence to a secondary phenomenon, which cannot be separated from all those which take place successively in the engine, and pretending to make of it the characteristic feature, and so to say, the turning pivot of the work of the engine.

The two converse facts : evaporation, condensation, may succeed and even superpose each other in the course of the expansion : *evaporation*, by contact with the sides, condensation distant from the sides. The direction of the general result depends on the temperatures in presence, steam and sides. In general the evaporation commenced later in M. *V. Grimburg's* experiments than in M. *Bauschinger's*, and it is according to the first, to this circumstance that some of the diagrams taken by him owe a characteristic form, that of a ship's bottom, of the portion corresponding to the expansion. The curve ceases to go down at one point, which would indicate the beginning of the evaporation, then it rises, rapidly indeed, as is shown by figures 6 and 7 (Pl. XVII).

By the very fact that it commenced late during the expansion, the evaporation must be continued during a portion of the exhaust, to the great detriment of the back-pressure. This is what would be shown by the initial value of that back-pressure, almost equal to the useful pressure at the end of the preceding stroke, and slowly decreasing; in a word, the

form at the same raised up and very pointed of the area of the right hand portion of the diagram.

But M. *Grimburg's* explanation does not appear to us admissible. He points out that this form of the curve of expansion only applies to long admissions; that the cylinder is in that case highly heated at the expense of the steam; that the speed of the piston being very small towards the end of its stroke, the volume of the steam increases then very slowly, which tends to keep it at a high pressure and temperature. It is quite natural that the formation of a new quantity of steam should check the progressive lowering of the pressure, but we seek, without finding it, the new source of heat which can, from a certain point, determine the increase of that pressure, decreasing until then?

Let us add that this series of experiments is, to our knowledge at least, the only one in which the expansion-curve presented that peculiarity.

Further : out of the 200 diagrams taken off in pairs (an indicator on each side of the piston), by M. *Grimburg*, only nine (nos. 48 to 56) are in this case, and, a singular thing, these nine diagrams were taken from the indicator applied at the back side of the piston. Is it then in the influence of the rod, that the cause of the observed rise must be sought? No, doubtless. The mass of the rod is relatively small, and besides, all the part that enters into the cylinder from the end of the admission, comes from the outside, and is consequently little heated.

These observations seem to us to warrant the presumption that we are in presence of an anomaly, affecting the indicator applied on the back of the piston, or of a leak. We look on it as idle to discuss a fact, the reality of which, as regards the law of the pressures, appears to us in no way established, nor even possible.

In M. *Bauschinger's* diagrams, the rapid lowering of the curve shows that the evaporation ceased before the end of the expansion or, more correctly speaking, before the beginning of the exhaust lead.

328. *Observation on stationary engines.* The evaporation during the expansion, in engines with a single cylinder and unjacketed, has been observed by many engineers. We shall take the following example from M. *A. Mallet's* study on the new marine steam-engines (*) :

Non condensing engine. The diagram (fig. 8, Pl. XVII) refers to a real expansion of 14 volumes. Absolute initial pressure 2.75 ats. " The tension at the end of the

(*) Page 71.

stroke should ", says M. *Mallet*, " be, according to Mariotte's law, considerably below the pressure of the atmosphere. It is seen to be no such thing. The pressure which, as soon as the port is closed, rapidly decreases, and approximates afterwards to the horizontal, and is formed again, at the end of the stroke, notably above the atmospheric line. *This effect is due to the evaporation during the period of expansion of the water contained in the cylinder*, which furnishes a supplement of steam the tension of which is added to the original tension.

Without dwelling on stationary engines, which would take us away from our subject, we shall cite further, according to M. *Schmidt* (*) an observation made by M. *Otto Müller* at Pesth on a high pressure engine, with great expansion. He recorded during that period, an increase of 20 per cent in the quantity of steam.

M. *Hirn* has perfectly established that the first condition, in order to analyze what takes place in engines, is to restore to the sides their main part as sources of heat. " I have supposed ", says he (**) after having exposed the properties of the theoretical cycle, " perfectly impermeable to heat, the sides of the cylinder in which we have effected the expansion and the compression of the steam. Now this condition is by no means fulfilled in thermal engines; and the action of the sides is such in those motors that we shall never require to have recourse to the various equations which are developed in these paragraphs. »

" The influence of the sides ", he says elsewhere (***), " is far too powerful for abstraction to be made of it, without involving considerable errors. On the other hand, that influence, easy to point out and to characterize under a general form, is on the contrary most difficult to express *a priori* in numerical values. "

After having (****) analyzed completely the work of the steam in two stationary engines, he compares in these terms, with the results obtained, those which would be obtained by neglecting the action of the sides :

" 1st, An error of from 30 to 60 per cent in the estimate of the expenditure of steam, seeing that the expansion would be supposed to take place without addition of heat;

2nd, A considerable error in the value of the work furnished by the expansion;

3rd, Lastly, an error, more considerable still, in the very use of the available heat, seeing that no account would be taken of the heat ceded to the steam at the moment of condensation.

(*) *Zeitschrift des Oesterreichischen Ingenieur vereins*. Year 1875, p. 25.

(**) *Exposition analytique*, vol. I, p. 340.

(***) *Exposition analytique*, vol. II, p. 80.

(****) *Ditto*, page 80.

" The most disastrous cause ", he says further (*), " of the loss of heat in steam-engines, is the instantaneous evaporation of the water which remains all along the sides of the cylinders at the end of the stroke, and at the moment when the exhaust into the condenser takes place. "

Thanks to the recent (in 1876) publication of vol. II, of M. *Hirn's* work, engineers have now at their disposal examples of complete and exact analyses of the *phenomena which take place in engines*. Able physicist, able engineer, living in the midst of steam-engines, who is better qualified than he to connect the facts with the principles? We refer the reader then to book IV of that most instructive work.

The changes of state of the water, the interchange of heat affected between it and the sides, in part with finite falls of temperature involve, by that very fact, losses of yield. It the evaporation which takes place during the expansion raises the curve and augments the useful work of that period, the precipitation during admission has reduced the work corresponding to the latter. But, it is mainly, as will be seen in a moment, to the third period that the most serious loss corresponds, if no step be taken to lessen it.

Two other divergences which coalesce or superpose, affect the second period.

1st. The expansion is not complete;

2nd. The establishment of the communication of the steam with the cold source does not coincide with the beginning of the return movement of the piston, or in other terms, of the reduction of volume of the intermediate body losing heat at constant temperature. It precedes that moment, especially in locomotives, where the exhaust lead is considerable, particularly when they run with small admission. Hence a loss on the work of the expansion, but as we have seen in the study of the distribution, this loss is more than compensated, especially at high speed, by the reduction of the work of *back pressure* during the normal exhaust.

379. III. *Escape. Back pressure.* Instead of contracting in a closed space, and so preparing therein its reconstitution into the initial state, the steam (to keep to non-condensing engines) (**), the steam is cooled, and set free into

(*) *Exposition analytique*, vol. II, page 65.

(**) Marine engines provided with a surface-condenser are those which approximate most nearly to the conditions of the theoretical cycle; but the work of the pumps which determine the circulation of the water around the surfaces of the *condenser*, is considerable.

the atmosphere, a loss which has to be made good afterwards at the expense of the work of the engine, and of the heat of the fire-box (380). But it must be expressly remarked that the theoretical cycle, operating indefinitely on the same water, would exclude the draught by the waste steam, that is to say, the most economical method, far preferable to steam taken at a high pressure directly from the boiler.

In condensing-engines especially, this period is subject to the cause of loss to which we were just now alluding (378). If the water deposited on the sides of the cylinder is completely evaporated during the expansion, it has not had, altogether, a very appreciable detrimental effect; but otherwise, if water remains in notable proportion when the exhaust opens, it evaporates rapidly by the very effect of the vacuum, and as has been already said, at its expense, in cooling greatly the sides of the cylinder, on which forms an instant after, during the admission, a condensation all the more abundant.

As we have already said (124), the back pressure may be neglected in locomotives the distribution of which is well regulated. It would only be otherwise for a large admission, joined to a high speed, circumstances which, in fact, exclude each other. If, at the beginning of the return stroke, the *back pressure* has a notable value (reduced, at the same time by the expansion, and by the exhaust lead), it soon falls almost to nothing, and remains nearly nothing until the *compression* commences.

It was not so formerly, in the time of coke, of small fire-boxes, and throttled exhausts. Then, in effect:

" In locomotives where the exhaust takes place through a pipe, the depression from the cylinder to the atmosphere often *reached* from 1/2 to 1 atmosphere. "

Thus does M. *Ledieu* (*) express himself, but speaking in the present.

Locomotives are frequently quoted, but they are often taken at fifteen years back, and more.

380. IV. *Compression.* The fourth period of the theoretical cycle, the adiabatic compression, disappears almost entirely when the closing of the exhaust takes place a little before the arrival of the piston at the end of its return stroke.

The effect of this *divergence* is favourable to the work per stroke of the piston, since to the useful theoretical area, is added the area ADE (Pl. XVII,

(*) *Nouvelles machines marines*, 1876, p. 313.

fig. 9), which represents the work of the adiabatic compression. But the expenditure of fuel increases in a much greater proportion. The steam not being brought back to its primitive state, by the actual run of the cycle, it must be reconstituted by injecting water into the boiler by a feeding-apparatus. The work of forcing the water in is inconsiderable, especially with the injector. But if this water is taken in cold by the apparatus, whatever that may be, it lowers the temperature of the water, which must be made up also. It is in this that the loss chiefly consists. Thus the divergence in question is of little consequence when the water forced in is brought to a pretty high temperature by heat taken, not from the fire, but from the escaping gases.

Locomotives provided with a link-motion, that is to say, all actual locomotives, seem at first to depart less from the theoretical conditions, the smaller admission they run with, and of course the longer compression. The closing of the exhaust taking place soon enough to confine a considerable proportion of steam in front of the piston, the steam is compressed, not according to the adiabatic law (it deviates therefrom more or less according to the quantity of water it contains, and according to the action of the sides), but finally, approximating, in this respect, to the real cycle of *Carnot's* cycle.

As we have already said, the steam may, at the end of this compression, be found brought back exactly to its initial state, and even (146) at a higher pressure. The diagrams taken by means of the indicator from locomotives running with small admission have, in effect, the run, the general physiognomy of the trace of *Carnot's* cycle.

This analogy resulting from the compression is only, according to M. *Zeuner* (*), a deceptive appearance; it would even constitute, relatively to the theoretical cycle, a further divergence. This is perhaps going rather far; if the second adiabatic curve is wanting, it is to that divergence that the draught is due; and M. *Zeuner* himself has established that the compression in the free space, bringing back a part of the steam to the initial state, augments the yield, and approximates altogether the real cycle to the theoretical cycle. It is true that a prolonged compression necessarily supposes a great amount of exhaust lead, and consequently a corresponding divergence, at the end of the period of expansion; but it is not of much consequence, the curve during the anticipated exhaust going down little below the continuation of the expansion curve.

By comparing for the compression, as he had done for the expansion,

(*) *Théorie mécanique*, pages 526 and following.

the real curve to the various theoretical curves (376), M. *Bauschinger* ascertained (Pl. XVIII, *figs.* 9 and 10) that the agreement is no greater for the first than for the second; but the real curve, instead of being placed above the others is placed below. There again, the equilateral hyperbola (*Boyle*'s law, not traced on the figures) is closer to the real curve than the other theoretical curves, and especially than that of the *adiabatic* compression.

The real work of compression is less than the theoretical work or of adiabatic compression, because the sides absorb a portion of the heat given off. The raising of the expansion curve on the one hand, the lowering of the compression curve on the other, are in *themselves* favourable, seeing that they increase the useful area.

With the distribution by slide-valve, a very slight compression gives a greater useful area, that is to say a greater work per stroke of a piston of given diameter and stroke; but a greater compression, reconstituting a part of the steam, is favourable to the yield; and everything is reconciled, power and yield, by giving the cylinders sufficient dimensions.

By the very fact that it keeps a portion of the sides of the cylinder in prolonged contact with the hot steam, the compression is favourable to the work of the steam during admission; it diminishes the fall of pressure, and the condensation on the sides.

M. *Zeuner*, we have just now recollected it, has proved (*) that with a compression regulated in such a manner that at the end, the pressure of the mixture may reach that of the boiler, *the engine works as if the clearance-space being nothing, the exhaust continued until the end of the stroke.*

The pressure, at the end of this period, may exceed not only that of the valve-box, but even that in the boiler. The diagrams often show this to be the case (**); but this excess should be avoided, it goes beyond the object in view.

Elevation of temperature due to the adiabatic *compression of dry saturated steam.* Supposing the adiabatic compression, that is to say all the heat produced passing into the steam, there would be, as we know (369), at first an evaporation if the steam were damp, and immediate superheating if it were dry. In this second case, the elevation of temperature τ would be given by the equation :

$$\mathfrak{C} = \frac{P \times c_1 \times \tau}{A},$$

(*) *Théorie mécanique de la chaleur*, p. 534.

(**) It is not a question here of the undulations of the curve resulting from the inertia of the indicator-piston, and perhaps from the vibratory movement of the steam itself. The run itself of the curve does not allow of confusing with real excess of statical pressure, the effects of these two causes, and especially of the first.

$\mathfrak{C}$ being the work of compression, given by the indicator, P the weight of dry steam compressed, and c_1 its specific heat at constant volume, that is to say $\frac{0.4805}{k}$, the specific heat of steam at constant pressure, c_1 being according to M. *Regnault's* experiments, 0.4805. But the value of τ thus obtained would be very exaggerated. On account of the action of the sides, it is, as for the expansion, the reverse of the theoretical effect takes place, that is to say a *condensation*.

Besides, the exact value to be attributed to k is not known; M. *Combes* admits 1.40, whence $c_1 = 0.343$; and *Rankine* $k = 1.30$, whence $c_1 = 0.37$.

It is only by the composition of the mixture at the moment when the exhaust shuts, that its internal heat can be established, and consequently, what passes during the compression. M. *Hallauer* has recorded (*) in condensing-engines with a single cylinder : 1st, that the steam still contains at the end of the expansion, even when there is a steam-jacket, a proportion of from 10 to 15 per cent of water, the greater portion of which is deposited on the sides of the cylinder; 2nd, that a part only of that water is evaporated during the escape into the condenser, so that the steam is not dry when the compression commences. But in non-condensing engines, such as locomotives, supposing this proportion at the end of the expansion to be known, what has become of it at the beginning of the compression? M. *Bauschinger* considers it nearly certain that the steam is then dry, if not even superheated (**). He bases this idea on the fact that, already partly dried during the expansion, it is found suddenly subjected to a lower pressure, and comes into contact with sides, the mean temperature of which is without doubt superior to its own.

The composition of the mixture might be determined by M. *Hirn's* calorimetric method, to which we shall shortly return (384), and which may be applied to the steam coming out of the engine, as to that coming from the boiler, and to the steam which passes off into the air, as to that passing into a condenser; but no determination of this sort has yet been attempted.

381. *Theoretical weight of steam per horse-power and per hour.* A *perfect* engine with two sources at the temperatures T and $T' < T$, expending per hour a weight P lbs, of dry saturated steam, at the temperature T, would develop per hour a work expressed in horse-power.

(*) Compression of steam in the clearance spaces. *Revue universelle*, 1873, 3rd part, p. 642.

(**) *Indicator Versuche*, p. 130.

$$\text{N h. p.} = \frac{P}{3.600 \times 75} \cdot \frac{r}{A} \cdot \frac{T - T}{T}$$

$$\text{whence } \frac{N}{P} = \frac{1}{270.000} \cdot \frac{r}{A} \cdot \frac{T - T}{T}, \text{ and for } A = \frac{1^{cal}}{124},$$

$$\frac{N}{P} = 0{,}00039\, r \frac{T - T}{T} \text{ or } \frac{P}{N} = 256.5 \frac{T}{r\,(T - T')};$$

r heat of evaporation has for expression : $r = \rho + A\,pu$, and M. *Zeuner's* table X (*) gives ρ and $A\,pu$.

Examples. We take from his work (**) the table of the values of P corresponding to N = 1, that is to say of the weights of dry saturated steam producing a work of one horse-power per hour in perfect engines, either non-condensing, or condensing. For the latter, T′ has been taken = 115°, 18, the temperature of saturated steam at 0.1 at.

TENSION in absolute atmospheres.	WEIGHT OF DRY SATURATED STEAM PER HORSE-POWER AND PER HOUR.	
	non-condensing.	condensing.
1 1/2..... T = 233°.13	73.07	15.60
3..... T = 273°.04	32 81	13.72
4..... T = 291°.20	26.28	11.85
5..... T = 307°.00	22.90	11.28
6..... T = 318°.59	20.75	10.86
8..... T = 339°.46	18.12	10.30
10..... T = 356°.56	16.54	9.91

Return from the fuel (Duty). The best condensing-engines, working at high pressure, consume per effective horse-power and per hour, 2.2 lbs of coal, and from 15.4 to 17.6 lbs of steam more or less moist, instead of the theoretical figure 9.9 lbs, about, of dry steam.

2.2 lbs of coal develop 27.720 units of heat = 27.720 × 772 = 21.402,840 foot-pounds. One horse-power = 550 × 3600 = 1.980.000, or less than 0.1.

The lowness of this figure arises :

1st, and mainly, from the boiler receiving only a portion, often about one-half, of the heat set free by the combustion ;

2nd, from the real quantity of steam corresponding to one horse-power greatly exceeding the figures in the above table, corresponding to the perfect cycle ;

3rd, from the resistance of the organs absorbing a considerable quantity of work.

(*) *Théorie mécanique*, p. 543.

(**) *Ditto*, 462.

§ VI. — Water carried over by the steam.

382. We have seen that the water condensed during the admission comes in afterwards by its evaporation, and performs, under the influence of the sides and of the piston, an important part. The phenomena which really take place differ greatly from those pointed out by theory, supposing, as up to a certain point seemed natural, that the rapid succession of the movements does not allow the sides to take from or yield to the steam any notable quantities of heat; but experience has proved the erroneous nature of this hypothesis.

The cooling of these sides, and consequently the precipitation during the admission is less in engines without condenser. But in locomotives, the steam when it leaves the boiler is already mingled with a variable proportion of water, often very great, in consequence of the conditions, to a certain extent excessive, under which the evaporation is effected.

The mode of action of this water mixed with the steam, thus disseminated throug ha medium the slight conductibility of which protects it, differs in certain respects from that of the water which, deposited on the sides, undergoes their action immediately and rapidly, as soon as the temperature of the steam has become lower than theirs.

Its economical influence. A most incorrect idea was and often is formed, of the economical consequence of this mixture with the water carried over.

It was quite understood that a certain original moisture of the steam was useful, necessary indeed; that steam at high pressure, saturated but dry, would be in spite of its condensation in contact with the sides, detrimental to the preservation of the rubbing parts, and would aggravate the resistances of the machinery; but save this useful side, the water mixed with the steam was and is still looked on as absolutely inert, carrying off in pure loss the heat which corresponds to its temperature — that of the steam — and as increasing the resistances undergone by the joint current. Thence, the frequent attempts made formerly, either to measure, or chiefly and with little success, to diminish the proportion of water carried over (38).

We know however at this day, we have already stated it (30), that this water, even in very great proportions, does not cause, in general, any notable loss of heat; but it is going too far to regard the fact as absolute, without any restriction.

From the point of view of the theoretical cycle, the absence of all influence of the water mixed on the yield would be an immediate consequence of this

general principle (373), that the nature of the intermediate body is absolutely indifferent.

By looking from a less abstract and more practical point of view, the fact is accounted for by remarking that the water mixed is at every moment at the temperature of the steam: it cools with the latter. If it does not contribute directly to the production of work by its expansive force, it assists therein by the intermedium of the steam itself, in the midst of which it forms a reserve of heat which it cedes to the steam successively, in proportion as it expands.

" M. *Zeuner* has calculated according to his formulæ, " says M. *Combes* (*), " the quantities of work furnished by the same quantity of heat transmitted to the boiler of a steam-engine receiving steam at a pressure of 6 ats and at the temperature of 307°2, which expands to a temperature of 233° 13, when the piston supports a back pressure of 1 $\frac{1}{4}$ at., according as the steam is absolutely *dry* or charged with water in the proportions of $\frac{1}{10}$ th. of the total weight. Having found that the work obtained ought to be the same in either case, he believes he can conclude that the carrying over of the water has no detrimental influence in engines working expansively. "

In reality M. *Zeuner's* conclusion is much less absolute. He finds (**) for steam with 0,15 of water at 4,5 ats. expanding to 0,1 at., an increase of consumption of fuel 0,03, relatively to dry steam; but this increase would augment for a greater proportion of water.

M. *Hirn* remarks that the small influence of the water carried over is confirmed by the experiments of the " *Société industrielle de Mulhouse.* "

M. *Combes* (***) has, himself, calculated the theoretical report of the heat utilized to the heat expended, for 1 lb. of steam at 302°, and at a pressure of 4,7 ats. expanding to 212° without *addition or subtraction of heat*, and sent into the atmosphere, after having utilized, in order to bring the feed-water up to 212° a portion of its heat. This calculation has been made : 1st, for perfectly dry steam ; 2nd, for steam carrying over 0,3 of water (a proportion hardly exceeded even in locomotives). He found for this ratio exactly the same value in the two cases.

The importance of this equality must not be exaggerated, because the calculation supposes the expansion *adiabatic*, which is not the case, and makes abstraction of the passive resistances.

On the other hand, as M. *Combes* points out (****), the coincidence is due

(*) *Exposé des principes de la théorie mécanique de la chaleur*, p. 157.
(**) *Théorie mécanique*, p. 509.
(***) *Exposé des principes de la théorie mécanique de la chaleur*, p. 158.
(****) *Ibid.*, p. 161.

to the compensation, accidentally exact, of causes which act in a contrary way For greater amounts of expansion, it would no longer take place, and that to the disadvantage of the moist steam.

" We see ", concludes the author, " that the carrying over of water, even in a very great proportion, exerts no appreciable influence either on the useful effect, or on the running of ordinary engines, in which the steam only expands in a space equal to four or five times its original volume. The only difference of note consists in this, that for the same work obtained and an equal expenditure of fuel, the boiler which furnishes steam charged with water produces in appearance, not in reality, a greater evaporation. But the carrying over of water is detrimental in engines working with a great degree of expansion, in which the expansion of the steam would be from fifteen to twenty times its volume The presence of water in large proportion in the steam, may thus increase the expenditure of fuel, by about 14 per cent, and require further, that the speed of the piston be increased in the same ratio. "

The influence of the water carried over on the yield of the steam, is then, partly a question of the extent of the expansion. In order that the yield may remain the same, the proportion of the expansion must increase with the proportion of water; so that if the expansion is pushed as far as possible, with the steam relatively dry, very wet steam will necessarily have between the same limits a less yield, and more fuel would be required for the same work. But this effect only becomes appreciable, even with a proportion of water as much as 0,3, for amounts of expansion very superior to those which the mode of distribution allows to be produced usefully in locomotives. If the water carried over does not appear to have in those engines a very appreciable influence on the yield, it increases the expenditure of water, a secondary consideration, but which may be not altogether without importance, seeing that it leads to an increase in the capacity of the tenders. When it is very impure, water in excess becomes really detrimental; it forms in effect solid deposits in the valve-box, and in the cylinders, and increases the wear.

Without doubt, a proportion of 0,3 of water is in no way necessary: so much is not required for avoiding griping: but at least, there would be little interest in reducing it, by half, for example. This water is not, in effect, the principal cause which causes engines to prime, and compels the blow-off cocks to be opened, especially on starting after somewhat lengthened stoppages. The engine would still prime, only with less intensity, even with the steam at first dry, on account of its condensation on the sides of the cylinder.

On this point, as on many others, the mechanical theory of heat, which

is so often objected to as not having made any advance, has rectified ideas, which if not altogether false (it is, according to us, going too far to term them so), are at least greatly exaggerated.

Just to mention it in passing, is then such a service nothing? In order to discover the improvements of which steamen-gines are still capable, the primary condition is an exact knowledge of the phenomena which accompany their working. This knowledge, still incomplete, but which has made such progress the last few years, to what is it owing, if it be not to the mechanical theory of heat, and to the valuable numerical determinations of the physicists, and especially of M. *Regnault?* It is therein that practical men should seek guides and means to control their observations, under the penalty of exposing themselves to serious errors.

We do not fear to insist on what we have just brought forward, not only because the example is instructive, but also because the error was and is even yet very prevalent.

" In an experiment of MM. *Gouin* and *Lechatelier* ", said M. *Perdonnet* (*), " the water carried over with the steam was in too great quantity, *seeing that it came abundantly out of the chimney;* the total loss of pressure (in the cylinder) was 0.38. With dry steam it was only from 0.09 to 0.10. This example sufficiently shows the utility of the arrangements which prevent the carrying over of water by the steam. "

If too great a proportion of water, not stated however, really increased to this point the fall of pressure during the admission, a loss of yield would result therefrom, according to the theory of heat, seeing that there is a fall of temperature; but, as we have already pointed out on the subject of depression (374), the loss would not be estimated by that fall, the *vis viva* being restored afterwards under the form of heat during the expansion.

The results in question, go back, besides, to more than thirty years, which renders their correctness subject to suspicion. The consequence which M. *Perdonnet* deduced from them ten years ago, is still admitted by *many* specialists among us. If the question of the carrying over of water and of the means of overcoming it is allowed to slumber, it is not from a conviction of its secondary importance, it is the engineers are because weary of the discussion.

According to the *Guide du mécanicien* (p. 121), the water carried over, among other disavantages, presents the following :

" It escapes only after having absorbed a notable quantity of the heat developed in

(*) *Traité élémentaire des chemins de fer*, vol. III, p. 466.

the fire. It increases the density of the steam, and, consequently, the friction of the pipes, and prevents advantage being taken, in the cylinders, of the whole pressure produced in the boiler; it creates, by the same movement, very considerable resistances behind the piston, by the friction developed in its passage through the ports and in the exhaust-pipe. "

The same ideas seem to be current in the United States :

" Experience has proved " says M. *N. Forney* in his *Catechism of the locomotive* (p. 110) published in 1875, " that moist steam is much less efficient than dry steam. "

And further on (p. 488), to this question : What is the economical effect of steam which *primes*, on the consumption of fuel ? " replies :

" It involves a great loss of heat, first because the hot water passes through the cylinders without *producing work*, and afterwards because the steam, mixed with a great quantity of water, does not flow as fast and as easily on its entrance into the cylinders and on its exit as dry steam. Whence it follows that the motor pressure on the pistons is smaller, and the back pressure greater than when the steam is dry. "

This is deciding the question very lightly. An opinion which is not based on well established scientific principles, should at least be in a position to point to some experiments.

It is not without surprise that we read, in M. *Ledieu's* recent work(*), the following passage :

" Locomotives *can only work* at 9 ats by employing steam *extremely aqueous, to the great detriment of economy in the consumption of fuel.* "

There are, in these two lines, two errors; the one, stereotyped, we see, aggravates the expression of the reproach addressed to the water carried over.

The author supposes that very wet steam is systematically employed in locomotives. It is nothing of the sort. It is tolerated, that is all, because it cannot be helped ; and it is very well known that this steam, extremely watery, is not necessary in order to run at 9 ats. We may add indeed that, every thing else being the same, the proportion of water diminishes, very probably, when the pressure rises.

" Water carried over is detrimental ", says only M. *Audenet* (**), " from the point of view of a good use of the fuel, and it may, if abundant enough, determine the breakage of the engine, or at least its complete stoppage. It must therefore be prevented at any cost. "

(*) *Nouvelles machines marines* by *M. Ledieu*, 1 vol. 8vo. with atlas, Dunod, Paris 1876, p. 183.
(**) *Etudes sur les chaudières marines*, p. 37.

Altogether, if as regards stationary engines, in which the expansion is often pushed very far, and in marine engines, the reduction of the proportion (much less however than in locomotives) carried over by the steam is yet an object worthy of being followed up, scarcely as much can be said for locomotives.

We have already seen (38) that the old methods of estimating applied to locomotives were excessive, especially when the condensation during admission was considerable, because the water thus condensed in the cylinder was confounded with the water really brought over from the boiler. We see to what figures this method of proceeding would have led for condensing engines with one cylinder, in which the precipitation in the cylinders attains the proportions we know (374, p. 754)! The method now applied to these engines gives, in experienced hands, very exact results, but it appears scarcely applicable to locomotives during running, so that a simple means of determining appropriate to these engines is wanting. From the point of view of the yield, this want is not of much importance; there would however be a certain interest in supplying it, and in knowing, at need, what are the proportions of water carried over.

Let us first mention, simply to call it to mind, a means specious enough, but doubtless neither simple nor very exact.

383. *Evaporation in the open air.* It is founded on the supposition that the carrying over of water is perceptibly nothing, when the evaporation takes place in the open air. This may be all very true, the more so as if it be a question of a locomotive, the steam produced, no longer creating the draught, the combustion is slow, and the specific evaporation very slight, which reduces the amount of water carried off.

The principle admitted, the gross evaporation might be ascertained of a given fuel in the engine when running, then its real evaporation in the open air with the engine at rest. The difference would represent the water carried over; but up to what degree would the condition of evaporation in the *open air* be fulfilled? Would it be sufficient to remove the valves? Would it be necessary to take off the cover of the dome? etc.

Mr. *R. Wilson* cites (*) certain stationary boilers which give, under a very small pressure however (2.8 ats), *gross* evaporations of from 10 to 12 times the weight of the combustible, and in the open air 5 times only. The quantity of water carried over would thus exceed that of the steam, and

(*) *A treatise on steam-boilers*, p. 301.

the proportion would be far greater in English locomotives, which, according to the same writer, give *gross* evaporations of 16 and 17 for one of fuel.

The quantity of heat necessary for the production of steam is very nearly independent of its pressure, but the method proposed admits gratuitously that the boiler absorbs in the two cases the same fraction of the heat set free by the fuel.

384. M. *Hirn's method.* This is the one applied also by this eminent engineer (355) to the determination of the heat (Q') given up to the condenser in engines. It consists in condensing a given weight of steam in a calorimeter the initial and final temperatures of which are taken, and in measuring the increase in the weight of the apparatus. The statical pressure of the steam being very exactly ascertained, M. *Regnault's* tables give the heat contained in the unit of weight of saturated dry steam, a heat of which a portion is transformed, during the discharge, into *vis viva* on account of the great velocity of the steam, to return afterwards into the state of heat by the extinction of that velocity. The temperature of the water of the calorimeter is measured by an air or rather a nitrogen thermometer with large scale. The weight of the calorimeter filled with water, which is from 50 to 53 lbs, is measured to 0.0035 of an ounce, by *Kœppelin's* hydrostatic balance :

K being the total weight of the mixture received in the calorimeter;

m the portion of this weight consisting of water carried over;

N the initial weight of the cold water in the calorimeter and of the apparatus itself and its appurtenances, converted into water;

t_0 the temperature of the steam on its entrance into the calorimeter;

t_1 the initial temperature of the latter taken by mercurial thermometer;

t_2 its final temperature taken by the air-thermometer;

q_0 the heat of the liquid corresponding to the observed pressure of the steam and to its temperature t_0;

The weight m is given by the relation (*) :

$$m = \frac{K\,(1092.1 + 0.305\,t_0 - t_2) - N\,(t_2 - t_1)}{1092.1 + 0.305\,t_0 - q_0}.$$

The following are the figures of an observation made by M. *O. Hallauer* (**) :

(*) *Note sur la construction du thermomètre différentiel à air. Disposition adoptée par M. Hirn. By O. Hallauer.* Pamphlet in 8vo, 1874. (*Extracted from the Bulletin de Mulhouse.*)

(**) *Ditto*, p. 14.

K = 1.645 lbs.
N = 35.270 lbs.
t_0 = 316°,2 corresponding to the pressure : 85.25 lbs.
t_1 = 65°,5.
t_2 = 114°,8,
q_0 = 207°,44 units of heat.

Whence $m = 0.0593$ lb. or 3.61 per cent of the weight K of the mixture.

The series of experiments to which the preceding belongs was made on large boilers of 46 feet, with continuous feed, the water being brought to 228° by a *Green's* reheater (391), in which the pressure and level varied little, — in a word on boilers working very regularly. The proportion of water carried over, varied in them however from one to two (from 2.10 to 5.55 per cent).

Every thing else equal, this proportion increases with the activity of the evaporation. It is thus quite natural that it should be greater for boilers without reheater than for those which have one, where the gases only arriving in the chimney after being already greatly cooled down, produce a draught of slight force. Thus the gross evaporation, which, according to M. *Meusnier-Dolfus*, reaches 9.22 lbs per square foot of grate and per hour in the first, is of scarcely the one half in the others.

In the experiments made by that engineer on the stationary engines of the *Société Alsacienne de construction*, boilers of divers types, *Lancashire*, *Fairbairn*, and with water-tubes, gave an average of 2 per cent with a gross evaporation of about 4.30 lbs per hour and per square foot (*).

The use of the differential thermometer and of the hydrostatic balance has permitted these slight proportions to be determined, but they were inappreciable in the preliminary experiments made with a balance, though very exact, and with a mercurial thermometer reading to 1/5 th of a degree. At times indeed the result was negative.

The proportion is naturally much greater in locomotives, in which every thing contributes to increase it.

At the same time, on account of the much greater proportion to estimate, a sufficient approximation would be perhaps obtained with a simple exact balance, and a mercurial thermometer reading to 1/5 th of a degree. It is under this form that it would be desirable the experiments should be resumed. Although the question has lost much of its importance, at any rate of that attributed to it, it would not be without interest to be able

(*) Letter of the 21st Nov. 1874.

to decompose into its two elements, the total quantity of water contained at a given moment in the cylinder.

It would be necessary above all to know how to estimate the influence exerted by the water carried over, on the passive resistances, and to be in a position to attribute to it, at least an approximate value; it does not appear however, that this increase of resistance might be considered as compensated by the heat disengaged by the frictions.

CHAPTER IV

IMPROVEMENTS TRIED IN STATIONARY OR IN MARINE ENGINES, AND MORE OR LESS APPLICABLE TO LOCOMOTIVES.

We shall conclude this *book* by some observations regarding the improvements, for which locomotives are not so well adapted as stationary engines, but which are not absolutely inapplicable to them.

The endeavour should be to introduce, into a *real* cycle, the improvements which have for result the reduction of its divergences from the theoretical cycles of the same limits, and their consequences. Among these divergences, one of the most serious, by the effects it may bring about, is, as we have seen, the mutual action of the sides of the cylinder and of the expansible body, in the state of steam or of water. One of the improvements most adopted is the steam-jacket; this is the remedy, for what is most detrimental in them (378, 379), of the effects of those continual exchanges of heat, of which theory at first made abstraction.

§ I. — **Steam-jacket.**

385. The utility of these envelopes, through which the steam coming from the boiler circulates before entering the cylinder (unless there be a special communication, which is better), has been and is still much controverted. To supply heat to the cylinder, but taking it from the source itself, from the steam, seems all the less logical that the result is definitively to increase the external losses; the envelope, at a much more elevated temperature and with a surface much greater than the cylinder, losing much more heat.

Such was *Tredgold's* objection and it is assuredly well founded; but *Tredgold* only saw one side of the question. The facts must be examined more closely ; the duty of the jacket then, appears and if its utility does not seem contestable in principle, it may of course at times be small enough to escape observation.

" More than thirty years ago, " says M. *Hirn* (*), " *Combes*, by studying attentively a

(*) *Exposition analytique et expérimentale de la théorie mécanique de la chaleur*, 3e édition. *Paris, Gauthier-Villars*, 1876, vol. II, p. 17.

steam-engine the cylinder of which was fitted with a *Watt's* steam-jacket, ascertained that there was a loss of nearly 20 per cent on the work produced, when, instead of letting the steam first circulate through the jacket, it was directly turned into the valve-box.

" In the existing state of our knowledge in physics at that period, the fact observed and very accurately recorded by *Combes*, *remained without rational explanation*, and most engineers confined themselves to denying purely and simply what they were unable to understand.

" On this occasion at any rate, routine, once in a way, had a useful result. *Without giving themselves the trouble of finding out whether the use of Watt's jacket is or is not serviceable, most constructors have retained it because it has been the custom to do so since Watt.* "

If really, as M. *Hirn* says, the good effects of steam-jackets " were without rational explanation ", if among the constructors, " some denied what they could not understand ", while others trusted blindly to the authority of *Watt's* great name, this state of things ought to have been changed more than thirty years ago, by the publication of the *Traité de l'Exploitation des Mines*. Its author, M. *Combes*, " not only observed and recorded the fact ", but also perfectly explained it in that work. The *partial condensation* of steam during *admission*, the evaporating of the water during the expansion, the useful part of the jacket and main condition of that utility, all these points were set forth therein in the clearest manner. This may be judged of by the following passage (*) which to this day sums up the whole theory of steam-jackets.

" If any doubts still remain as to the partial liquefaction of the steam in the cylinders of Cornwall engines, it is not so as regards those of double action engines which are not surrounded by a jacket, or more generally exposed to an external source of heat. In these engines, in effect, the steam is admitted into a part of the cylinder which an instant before, was in communication with the condenser; now the rarefaction which the steam undergoes during the condensation, was necessarily accompanied by a lowering of the temperature, and by the cooling of the inside of the cylinder. This cooling will be especially considerable, if there remained any water at the moment when the communication with the condenser was opened, for that water would then be rapidly transformed into steam under the influence of the vacuum, taking from the side of the space wherein it is contained, the heat of evaporation. When afterwards, the steam coming from the boiler is again admitted, liquefaction will take place until these sides are reheated.

" If the steam is admitted during the whole stroke of the piston, no particle of water can repass into the state of steam, unless during the condensation. If, on the contrary, the engine works expansively , a part of the water evaporates afresh during the expansion.

(*) Volume III, p. 357, *Paris, Carilian-Gœury*, 1845.

" The heat carried off by the formation of the steam which rushes immediately into the condenser, is entirely lost. This loss, a *very serious one*, can only be prevented by submitting the cylinder to the action of an external source of heat which evaporates the water during the stroke of the piston (that is to say during the expansion), *and by this means greatly diminishes, if it does not completely check, the quantity of water precipitated during the admission of the steam.* "

If then, thirty years ago, the action of steam — jackets was not yet comprehended, if those who applied them did not know why they did so, it was not M. *Combes's* fault. But speaking truly, M. *Hirn's* opinion seems to be very severe on the engine-builders of that time.

The steam-jacket ought itself to be protected by a cover thoroughly isolating it from external cooling. M. *Combes* pointed out, in 1845 (*), the method adopted in single acting *Cornwall* engines, in which the steam-jacket is surrounded by a wooden case, leaving an annular space of 12 inches, between it and the cast-iron jacket, filled with sawdust.

The principle of the variable efficiency of the steam-jacket rests in its action on the water precipitated on the sides of the cylinders. The object to attain is that this water may be completely evaporated at the end of the expansion. If this is so, that evaporation is effected wholly to the gain of the *useful work*, while if water remains on the sides when the stroke returns, that is to say when the exhaust begins, the evaporation takes place, henceforward, to the gain of the back pressure, and in cooling, to entire loss, the sides which are to receive the fresh steam from the boiler.

Now the jacket acts : in the first place, during admission, by diminishing the quantity of water precipitated on the sides; afterwards, during expansion, by hastening the beginning and accelerating the progress of the evaporation of this quantity, thus reduced.

If the jacket stopped the condensation on the sides during admission; if, doing more than compensate the loss of heat of the steam during expansion, it maintained its temperature constant, there would be an *isothermal* expansion, the pressures and the volumes would follow very nearly *Boyle's* law (as far as it applies to steam). Some authors admit that in effect it does so. This law tends to become the more manifest, even in adiabatic expansion, the greater the proportion of water present (367), at least up to a certain limit; so that the jacket, reducing this proportion, would tend, in this respect, to conceal the law; but what is certain is that engines with jackets give most frequently, if not always, like those which have none, as

(*) *Traité d'exploitation*, vol. III, p. 492.

the locomotives cited, for example (376), curves of real expansion more or less, and often very superior to the equilateral hyperbola of *Boyle's* law; which proves that water is still present during the expansion, or at least during a portion of it.

This was so in the single action engines on which observations were made by M. *Combes.*

" The first hyperbolic arc " says he (*), " is constantly below the curve of the pressures of the steam given by direct experiment. "

These facts, he adds (**), which are not peculiar to one engine alone, are nothing but natural if we admit that there exists in the cylinders, at the moment of closing the admission, a small quantity of water which is transformed into steam during the period of expansion, and is entirely evaporated *before the end of the stroke of the piston.* This evaporation before the end of the stroke was deduced in this case from the slightness of the deviation between the second hyperbolic arc and the real curve.

We see that, in these engines, the jacket attained its object, viz. the complete evaporation, at the proper time, of the water condensed during the admission.

M. *Hirn* has shown that if the jacket diminishes this condensation, it by no means suppresses it; the condensation resists even the combined action of the jacket and a great amount of superheating, to 446° for example, of the steam before it enters the cylinder. Which at the same time is far from implying the immediate passage of all the steam at the point of saturation and even above it. It is not here a question of equilibrium, but of an entirely local action at the contact with the sides, which would perhaps permit the action of the superheating on the frictions to be less dreaded than it is.

The effects of the jacket on engines with a single cylinder have sometimes appeared almost null. In other cases, — and these are the most numerous, — they have been very satisfactory; it is thus probable that the null results ought to be attributed to the fact that some cause not explained concealed or hindered the effects of the jackets. Similar deceptions have been also experienced with engines having two cylinders. Mr. *Bramwell* (***) cites, according to *Sir William Thompson*, two examples of marine engines of the

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(*) *Traité d'exploitation*, p. 554.

(**) *Traité d'exploitation*, p. 557.

(***) Translation by *M. Mallet*, *Étude sur les nouvelles machines marines*, p. 43.

compound type, in which the jacket has been suppressed; to the one, on the large cylinder, — a suppression accompanied by that of the superheating cylinder and, for the other, on the high pressure cylinder, — which alone was provided with it. In both cases the consumption remained the same.

We have already pointed out (351) the partial opposition of the phenomena which characterize the two categories of engines, — with one and two cylinders, — when they work without jacket; for the first, *increase;* for the second, *decrease* of the quantity of steam during the period of expansion. Whence it might be concluded that the jacket is, in this respect, more useful still for engines with two cylinders than for others, seeing that we have to do with a quantity of water no longer diminished, but increased by the expansion.

But the single cylinder engine is, on account of the greater variations of temperature the cylinder undergoes, much more subject to an abundant precipitation of water during the admission. It is for that engine especially that the preventive remedy, the envelope, is necessary.

386. After presenting (351) the condensation during expansion " the principal source of the power of steam-engines", *Verdet* soon expresses an absolutely contrary opinion. We must quote him again, not to make him contradict himself, a man of such real merit, but because it is necessary to show how little his ideas as to what takes place in engines, were fixed and mature. For want of sufficient reflection on this subject, which he judged *a priori* must be very simple, he first falls into an error, which the authority of his name must have contributed to sanction; then under the impression of another fact, he gives up that error but without rectifying it, and indeed appears to have completely forgotten it.

" *The partial condensation which accompanies the expansion* " says he on the subject of *Watt's* jacket (*), " involves *serious disadvantages* in practice. The cylinder fills with water, the stroke of the piston becomes diminished by that very fact (?); beyond which this water substitutes, from the beginning, for dry steam a bad conductor of heat, a mixture of steam and water which is a better conductor, and there results a considerable increase in the loss by communication of heat to the outside. An arrangement due to *Watt* does away with disadvantages, by opposing the condensation during expansion.

" The steam which completely surrounds the cylinder, in the arrangement adopted by *Watt*, does not act only as an isolating envelope, it constitutes a source of heat by means of which *there is no appreciable condensation during expansion.* "

(*) *Théorie mécanique de la chaleur*, vol. I, p. 293.

Thus, this condensation during expansion, this happy fact to which the steam-engine "owes the greater portion of its motive power" (351), has become, on the contrary, *a serious disadvantage which it is of consequence* to do away with; and if *Watt's* jacket is of use, it is on account of suppressing this.

A singular contradiction in a mind so clear, and so precise, and the origin of it may perhaps be looked for in the posthumous publication of his otherwise remarkable work.

M. *Briot*, at the same time, does not escape either.

This is how he expresses himself on this head: *Watt's steam-jacket* (*).

"Watt conceived the idea of surrounding the cylinder with a second cylinder into which *the gases from the fire* (**) pass after heating the boiler, and before going up the chimney. These gases supply heat to the steam, and prevent the *condensation which habitually takes place during expansion.* The formation in the cylinder, of the condensed water which interferes with the progress of the piston is thus avoided, and the yield is increased with the necessity of increasing the combustible."

But how reconcile the passage which precedes, and which attributes the good effects of a jacket to the suppression of the *condensation during the expansion*, with that which points out on the contrary this same condensation as "the principal source of the force of steam-engines"? (351.)

The author afterwards considers an engine with full expansion in which the temperatures are 302° and 122° in the condenser, and he calculates the work per stroke of the piston:

1st, without jacket; 2nd, with jacket, the latter being supposed to keep the steam saturated but dry, until its arrival in the condenser. He finds, in the second case, an amount of work greater by $\frac{1}{11}$th, so that the work has increased, because the condensation during the expansion has disappeared.

M. *Regnault's* hypothesis of the steam remaining saturated up to the end of the expansion (350) was complained of. He had thereby, it was said, remarkably exaggerated the imperfection of engines; what did he do then with all that heat acquired by the valuable condensation which is effected during expansion?

And now, they do exactly what they complained of: and this *source*

(*) *Théorie mécanique de la chaleur*, p. 118.

(**) There is here a confusion between the steam-jacket and the envelope of hot gases which M. *Combes* pointed out could be substituted for it, but which appears not to have been employed by *Watt*. It is sometimes so at the present day. Example, the *Pollux* engine, cited by M. *Friedmann*, p. 63.

This explains why M. *Briot* admits that the jacket does not increase the consumption. It is a jacket inclosing gases lost from the pipes, he supposes.

of work which the great physicist had so unfortunately misunderstood, the question now is only of avoiding it at all costs!

To such contradictions people expose themselves when, in a series of phenomena which are bound together and converge to a final result, they take a particular fact, sometimes one, sometimes another, and consider it by itself, as if it comprised everything.

M. *Combes* remarks (*) that if *dry saturated* steam expanded by receiving the addition of heat necessary to prevent the precipitation which accompanies the adiabatic expansion, and to keep the steam at the point of saturation, there would be no gain, on the contrary; the increase of work obtained not being, by a long way, the equivalent of the heat added.

" Even were it possible to prevent by an addition of heat the *precipitation* of steam which takes place *during the expansion* in the cylinders of *ordinary engines*, it would be very disadvantageous from the point of view of economy of heat. If it is useful to keep the cylinders at the temperature of the boiler, by surrounding them with jackets and putting the intermediate space in communication with the boiler, it does not follow that the water carried over, or *that precipitated during expansion* is evaporated by the heat coming from the jacket. The fact is explained by the influence of the sides of the cylinder, which naturally cooled during the expansion and the condensation, determine at each new introduction, the immediate liquefaction of a portion of the steam hotter than they, coming into contact with them. "

Here again we see in what precedes, a fresh example of the confusion made between the *theoretical* engine and the *real* one. Once more, no precipitation takes place, *during the expansion*, in the cylinders of " ordinary engines "; it is on the contrary an evaporation. The author would have avoided this confusion if he had referred to the extract given further back (385) from his own work, in which the effects of the real engine are so exactly analyzed; it is true that at the period when he wrote, the *condensation* during the *adiabatic* expansion of dry steam was not known; and later, under the impression produced by that discovery, the author allowed himself to be led astray and to carry over the *effect* in question of the theoretical conditions, to which he devotes himself, to those of practice, in which it is the reverse effect which takes place.

387. *Applications to locomotives.* Locomotive engines are little adapted for the application of jackets, on account of the increase of weight and volume which they involve for the cylinders. M. *Polonceau* is the only one, I believe, who tried them in the course of the long series of experiments which he carried out, and to which his successor, M. *Forquenot*, has added

(*) *Exposé des principes*, p. 153.

so many useful researches. The application in question is described in an autographic memoir which has not been published, and from which I take the conclusions touching the envelope.

The cylinders of the engine (N° 93) 15.75 inches $\times$ 22 inches had jackets round the periphery only, and not on the bottom cover. The jacket received the steam from a pipe which took it from the steam-chest.

The conclusions deduced from the diagrams are the following.

1st. The jacket increases slightly the mean pressure during admission (*);

for an admission of 18 per cent of the stroke, that pressure was 0.83 of the pressure in the boiler
— 30 — — 0.85 —
— 42 — — 0.05 —

With or without jacket, the fall of pressure from the boiler to the cylinder diminishes with the speed, and it was *nil* when the mean speed of the piston was no more than 3 feet per second;

2nd. The jacket had very little influence on the work during the expansion. The author properly remarks "that there is produced during that expansion, an instantaneous evaporation of the water carried over and condensed during admission." But he adds, "with the multiplicity of strokes, the excess of temperature of cylinders with jackets over those without *ought not* to be such that any appreciable difference be produced between the two results."

Which amounts to saying that the speed is too great for the water to have time to profit by the supplementary heat supplied by the jacket to the sides; an explanation couched in dubious terms, and suggested by the similarity of the results given by engines 93 and 94.

Hitherto, every thing seems to point simply to an external source of heat too slight to give any notable gain, either during admission, or during expansion.

The *back pressure*, null with the jacket, was null already without it (124); there is nothing required from it for that period, contrary to what would take place in a condensing engine; it is particularly in the latter, for the benefit of this period that the jacket acts, as we have already said, by evaporating the water during the expansion.

But, from the point of view of the compression, the author of the report considers the jacket decidedly detrimental, because, although beginning later in engine 93 than in engine 94 (on account of the gradual and then total suppression of inside lap), the compression absorbs in the first a notably greater amount of work.

(*) Engine 93 was compared with engine 94 of the same type. It would have been preferable to compare it with itself, with and without steam in the jacket.

Without reopening here a discussion to which we have already devoted some space when studying the distribution of the steam, without stopping to examine what may be the influence on the tensions of the compression by superheating, which had so little bearing on the tensions of admission and of expansion, we shall limit ourselves to recal, that what is definitively necessary to know, is whether the jacket increases, not the work, the *useful* area per stroke of the piston, but the work per unit of weight of steam expended; a question which the investigations in question have not answered.

We could not therefore adopt the conclusion, drawn up in these terms (*):

" In substance, it may be concluded that as the distribution of the steam performed by *Stephenson's* link, necessitates an amount of expansion such that the admission may be from 0.20 to 0.30, the jacket is *rather detrimental than useful*, seeing that the advantages are reduced to a small increase of tension of the piston, and that the compression takes place in a much greater proportion. "

388. *Cylinders in the smoke-box.* Mr. *D. K. Clarke* very justly remarked, long ago, that the proportion of water and steam contained in locomotive cylinders varies at each moment, and that it depends, besides, on the position — interior or exterior — of the cylinders.

" When ", says he (**), " they are plunged into the atmosphere of the smoke-box, the temperature of which is in general much more elevated than that of the steam, the condensation is less than when the cylinders are not so heated. In this second case, there is condensation during the admission, which heats the cylinders. When the admission ceases and when, by the expansion, the temperature of the steam has fallen below that of the cylinder, the water deposited therein evaporates; so that what at first sight seems a useful property of cylinders not protected, that is to say this evaporation during the last degrees of the expansion, is nothing else than a *resurrection* of a portion of the steam precipitated in the beginning. "

A detrimental resurrection, if it continues during the return stroke, but less detrimental in locomotives than in condensing engines and with a single cylinder, because it is effected in less proportions.

The position of the cylinders in the smoke-box is the most simple form under which the jacket is applicable to the locomotives of Sharp and Roberts and their example has induced several other builders of inside-cylinder engines, to extend the smoke-box below, and thus inclose the cylinders, of which the front and hinder faces of the box were the immediate supports. But although irreproachable in principle, seeing that it

(*) *Autograph*, p. 68.
(**) *Railway machinery*, p. 82.

utilizes what would otherwise be lost, this position is not without disadvantages in itself, and independently of the considerations of pure mechanism to which we may not return. Thus, for various reasons besides, inside cylinders (which are however at the present time exceptions) are hardly ever put in connection with the gases of combustion [II, Pl. XXXI, XXXII (Northern of France), XXXIII, XXXIV, XLI and XLII (Western of France), LXIX, LXX (Eastern of France)].

§ II. — Superheating the steam.

389. A " disastrous " cause of loss of heat is, as we have seen (378), the presence of the water which, not being reduced to steam by the action of the sides during the expansion, evaporates during the exhaust. The steam-jacket suppresses or reduces this loss; the superheating of the steam before the admission contributes to the same; it struggles more or less efficiently against the cause of the evil, that is to say the precipitation during admission.

M. *Hirn* (*) sees the progress of the steam-engine in the simultaneous use of jackets with moist steam, and the superheating of the steam sent into the cylinders, to about 545°.

Professor *Rankine* (**) thus defines the multiple object of superheating:

1st. It raises the temperature (T) which the fluid possesses when it receives the heat from the source, " to raise the temperature at which the fluid receives heat, and so to increase the efficiency of the fluid, according to the principle of article 265. " This principle is the expression of the theoretical yield, an expression no longer applicable in this case, as we have seen (365);

2nd. It reduces the density of the motor steam, and consequently increases the vacuum in the condenser (***);

3rd. It prevents (without the use of a jacket) the *condensation* of the steam *during expansion*. These effects, he adds very justly, notably for the third, tend to increase the yield and to economize the fuel.

According to M. *Briot* (****), the use of superheated steam is " one of the

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(*) *Exposition analytique et expérimentale*, vol. II, p. 118 and 119.

(**) *The steam-engine*, 8th edition, 1876, p. 428.

(***) *Steam-engine*, 8th edition, p. 381. Professor *Rankine* recalls here consequences deduced by M. *D. Clarke* from his observations on locomotives, consequences that *Rankine* considers as applicable, probably to all engines, condensing or not. We do not reproduce them, *back pressure* being of no importance in locomotives.

(****) *Théorie mécanique*, p. 121 and 122.

most important improvements that have been made in the steam-engine", a statement which is too absolute, at least up to the present time.

He does not consider it, however, as preventing the *condensation* during expansion, a disadvantage which the jacket obviates at least (386).

"Although at first superheated", says he (*), "the steam soon becomes saturated during the expansion. *It partially condenses afterwards.*"

In locomotives, a simple drying of the steam has not yet been effected (38); and as it is agreed at the present time to regard moist steam as especially necessary in those engines, there would be little desire to apply regular superheating to them, even if this could be carried out.

The estimates *a priori*, of the effects of superheating fail in accuracy, because the numerical values for superheated steam, specific weight, specific heats and coefficient of dilatation, are not known. With regard specially to the period of expansion, there is no difficulty according to M. *Hirn*.

"We have been able", says he (**), "to examine in their minutest details the properties of the engine with superheated steam, without occupying ourselves in the least with the laws of expansion of this kind of steam. The reason is that on account of the powerful action of the sides of the cylinders, the steam, *however much it may be superheated*, is reduced to ordinary saturated steam."

Is the fact quite certain, and general? The return to saturation, does it take place at the beginning of the expansion? The condensation on the sides in no way implies, as we have already said (385) the state of saturation of the whole. M. *Combes* has shown in an interesting discussion, that the specific heat under constant pressure and coefficient of dilatation may vary between tolerably wide limits, including, almost with certainty, the real values, without the yield being appreciably affected. But in reproducing these estimates, we cannot help warning builders against their consequences.

M. *Combes* has calculated the ratio of the heat converted into work to the heat expended, for two steams very nearly at the same pressure, the one saturated, the other superheated, expanding to the same temperature.

1st. *Dry saturated steam* (***) at 302° (4.7 ats) expanding to 342°; feed-water at 112°. Calculation gives for the ratio in question 0.213, a figure nearly

(*) *Théorie mécaniqne*, p. 239 and following.

(**) *Exposition analytique*, vol. II, p. 296.

(***) *Exposé des principes*, p. 249.

identical with that which deduced from the expression $\frac{T-T'}{T}$ of the theoretical maximum yield;

2nd. *Steam at* 5 *ats.* Superheated to 464°, expanding equally to 142° (*); feed water at 112°.

Admitting for the specific heat under constant pressure c, 0.48051 (value found by M. *Regnault* under the atmospheric pressure and between 248° and 428°), and for the mean coefficient of dilatation, under the constant pressure of 5 ats from 308°.5 to 464°, the value $\frac{1}{250} = 0.004$, the ratio is 0.217. Admitting for c_2 the same value, and for α, $\frac{1}{273}$, the ratio varies only 1:1,0094 :: α having the same value, and c being supposed equal to 0.44, the ratio becomes : 0.218.

The superheating from 202° to 464°, would thus have no appreciable influence on the yield, the calculation of which we are giving the results, taking into account, of course, the heat employed in the superheating.

" We are thus led to conclude, " says M. *Combes* (**), " contrarily to the opinion generally prevalent, that the economy obtained by the use of superheated steam, under the ordinary conditions of the engines in general use, an economy the reality of which we do not contest, is due to the fact that the superheating is effected by the heat of the gases from the combustion, which would otherwise be lost; that it arises consequently from an improvement in the furnaces and from a better use of the fuel, and *not to the superheating itself.* "

This conclusion is too absolute, and often very defective. The calculation necessarily supposes the theoretical conditions; it makes abstraction of the action of the sides, and of the water precipitated during the admission of the saturated steam. It is on this account that superheating, even where the heat it requires is directly supplied by the furnace, and not by the lost gases, might considerably improve the yield. It may complete the effect of the jacket, if there is one, and make up for it, if there is not.

In treating, like M. *Combes*, a particular case, Professor *Rankine* (***) finds an economy of 15 per cent, in favour of superheating, supposing the heat it absorbs supplied by the furnace. " It would rise ", he adds, " to 23 per cent, the heat being furnished by the lost gases; this figure is confirmed by practice. "

(*) *Exposé des principes,* p. 239.
(**) *Ibid.,* p. 250.
(***) *Steam-engine,* p. 436.

There is nothing very surprising in this want of agreement between these estimates.

390. *Application to marine engines.* It is, of course, naturally to the lost heat that recourse is had for superheating the steam. In fact, without being prevalent, this improvement is receiving frequent applications, especially in the navy.

Without denying that superheating has the serious drawback of determining griping at times, many naval engineers attach a high value to the advantage which it presents of suppressing, or at least reducing the condensation in the cylinders, as well as the solid deposits which form therein (and which are avoided, however, by surface-condensers).

The dissentients are numerous however, even in the navy.

" The economy which should theoretically be produced by superheating with the aid of the hot gases from the chimney, " says M. *Audenet* (*), ship-building engineer, " is not demonstrated by practice; and it is, on the contrary, recognized that this superheating, the intensity of which it is nearly impossible to regulate, rapidly destroys the cylinders and slides. Perhaps if the pressure is increased still further, it may be found useful, to use steam a little moist, in order to preserve the organs, and soften the friction. "

Let us not hesitate to dwell a little on this.

This subject is somewhat obscure, and perhaps locomotives are more concerned in the question, as is supposed at present.

" At first, " says M. *Bramwell* (**), a high amount of superheating was given to the steam. At the present time it is generally given up. People are content with reservoirs of steam in the base of the chimney. The steam is thus simply dried, without being superheated to a point which may be troublesome for the preservation of the packing. "

In the Austrian navy, where the engines are on *Woolf's* system (compound), the steam from the boiler only arrives at the small cylinder, after having, either wholly or partially, passed through superheating apparatus. The second is the more usual case. The portion carried to a high temperature in the superheater placed under the chimney, mingles, on its entrance into the high pressure cylinders, with the moist steam which flows directly from the boiler (example, the vessel *Frisia*) (***).

(*) *Études sur les chaudières marines*, p. 41.
(**) *Studies on marine engines*, p. 27.
(***) M. *Friedmann's* report, p. 66.

In other engines, those of the *Pollux* (*) for example, the superheating takes place, not in the passage of the steam from the boiler to the first cylinder, but in the journey from the latter to the second. The steam being no longer in communication with the boiler, may attain a pressure more or less superior to that in the boiler.

A large pipe, taking a part of the gases from the smoke-box, leads them into a chest placed between the two cylinders and containing a great number of tubes in contact with the steam; the hot gases pass through these tubes, circulate through a jacket enveloping each of the cylinders, and return into the chimney.

With respect to the oscillating engines, on the *compound* system, of the *Société du Danube*, the high pressure cylinder is provided with an envelope in which the steam circulates before entering the cylinder. M. *Friedmann* remarks that this arrangement, though in general use, is not to be recommended when, as in the actual case, the steam is not superheated. He admits that oscillating engines can scarcely work with superheated steam. " But ", says he (**), " the steam-jacket is not sufficient for preventing the partial condensation during admission, and its consecutive effects.

Even if the jacket alone were not sufficient, that would be no reason for condemning its application to engines not adapted for superheating, the utility of which is so strongly contested. It would at most be an argument more or less weighty against oscillating engines, a question which we have not to discuss here.

" In the majority of marine engines, " says the same engineer ( ), " the temperature of the gases which leave the boiler is over 750°, but that is a disadvantage which cannot long exist, and as in a good boiler the gases ought not to escape at a higher temperature than 480°, this temperature, which the packing of the cylinders bears very well, seems for the moment to be the rational limit of superheating. " (***)

Is not this limit of 480° too high for the packings? Is it not, on the other hand, too low for the draught by the chimney? of which specialist engineers complain as being too weak with much hotter gases? Would it be possible to lower their temperature from the first figure (750°) to the second (480°) and to take heat from them for the benefit of the motor? In condemning the first point, it seems that the second would imply the transformation pointed out farther back (366), and so imperiously demanded from sever-

(*) M. *Friedmann's* report, p. 67.
(**) M. *Friedmann's* report, p. 72 and 73.
(***) M. *Friedmann's* report, p. 70.

al points of view, by many naval engineers, that is to say the substitution of a forced draught for the natural one.

Altogether, railway engineers ought to consider the examples given by marine engines, and keep themselves well up in the uncertain state of the question of superheating. The two categories of engines, analogous in their functions, as in certain conditions of their installation, have already usefully borrowed from each other; and many do so still.

In any case, the high pressures reached in locomotive boilers, and which predispose to griping of the organs, only leave doubtless a very small margin for the application of superheating.

§ III. — Heaters for the feed-water.

391. The heat carried off by the gases into the chimney constitutes a very considerable loss. In stationary engines this heat supplies, it is true, the work necessary for the draught; but experience proves that the temperatures of the gases can be greatly lowered without ceasing to be sufficient for that purpose. It is not so in marine engines, where the metal chimneys only produce a draught already regarded as insufficient, and on which an increase of height, beyond adopted limits, would have no appreciable influence. According to M. *de Maupeou*, author of the paper quoted further back, it is the fear of weakening the draught which has prevented the use of *feed-water heaters* in the navy.

In locomotives, on the contrary, taking heat from the gases seems all the more expedient as the work of the draught is done by the blast, and as the gases, while leaving the boiler at a very elevated temperature, at 660° and even higher, are no longer suitable for the direct production of steam, especially at a high pressure.

The difference between the temperatures of the smoke and of the boiler is not great enough; little is gained by bringing, as is often done, gases relatively much cooled into contact with the water at the high temperature of the boiler. Instead of obtaining, by tubes too long, and at the cost of an appreciable increase in the weight and in the wheel-base of the engine, an almost nominal increase in the heating-surface, it is much better to stop the direct action of the gases on the boiler sooner, and to make them act on the feed-water, which is relatively very cold and quite adapted to rob them of their heat.

It is thus heated, before entering the boiler, by heat which would be other-

wise lost, instead of after its entrance therein, at the expense of the fire, and (what is worse still) by producing, during great feeding, abrupt effects of local contraction, so injurious to boilers.

For stationary engines, the heaters have long given excellent results, for example throughout the whole *Mulhouse* district. Here it is not a question (though it matters little) of tubular boilers, which at *Mulhouse* are generally disapproved of (perhaps rather too much so), chiefly on account of the incrusting nature of the water.

M. *Hirn's* heater was a spiral tube of copper placed vertically in a cylindrical chamber. The smoke leaving the flues entered the chamber at the top, quitted it at the bottom and went into the chimney, while the feed-water entered the serpentine by the bottom, left it at the top, and then passed into the boiler.

At the first trials, a fan drew the gases into the chamber of the serpentine, and from there into the chimney; but experience quickly proved that the fan was useless, the natural draught of the cold gases being still sufficient, especially with the dimensions given to the chimneys, to which a minimum of height is often obligatory from other considerations.

The apparatus, formed of tubes one over the other, was afterwards placed under the boiler. The diameter of the tubes is 4 inches inside and 4.4 inches outside.

But in spite of their small diameter, the tubes are not stopped up, as might have been feared, with incrusting water. The pressure to which the water is subjected prevents the disengagement of the carbonic acid in excess, which would immediately result from heating without pressure.

Green's reheater or economizer, an old apparatus still very much used in England, is composed of two horizontal chests in cast-iron, connected by vertical tubes. That of *Sulzer frères*, is composed of two long longitudinal boilers, each terminating at the hinder end, in a cast-iron serpentine.

Some coal causes on the sides of the heaters a deposit of soot, which appreciably reduces their action, but which at the same time, is scarcely produced except when the proportion of air in excess is small. Now we have stated that the tendency on the part of stokers is rather to force that proportion, and why it is so.

By dwelling a moment on this point, we shall not really be digressing from our subject, as the observations made on stationary engines should be the starting point of possible applications to locomotives.

In boilers without feed-heater, the yield of the fuel water evaporated) is always greater the more the draught is reduced. That is, the less the excess of air, the less the loss of heat carried off by the gases of combustion. With the heater, the yield *seems* the greater, in proportion to the excess of air.

At *Mulhouse*, the heater increases the yield by 10 per cent (7.58 lbs brought to 8.38 lbs). The stokers manage their fire so as to take in 230 cubic feet per lb. of coal.

In the boilers with three water-tubes and heaters, tried by the engineers of the *Société de Mulhouse*, they admit that the heat is thus divided :

61 per cent in the steam;

8 per cent lost on account of incomplete combustion (this figure includes *cinders*, which are often estimated at 3 per cent of the fuel).

8 per cent passing up the chimney, carried away by the gases (out of the 8 per cent, 2.50 per cent correspond to the evaporation of the water arising from the combustion of the hydrogen of the coal).

23 per cent absorbed by the masonry.

Altogether, in the best established boilers, only from 60 to 65 per cent of the available heat of the fuel is utilized.

According to the same engineers, it is chiefly in the inside fire-boxes that an improvement of this state of things should be looked for.

In locomotives, the conditions are by that very fact more favourable. It would remain to apply a heater to them, and there would not appear to be serious difficulties in doing so.

As we have said, the heating of the whole mass of the water of the tender, effected by a partial and variable condensation of the exhaust steam, does not deserve the attacks of which it has been the object; but it was, unquestionably, a not very rational method. What is the use of heating the water previously, and especially a long time previously, to allow it to radiate afterwards? It is at the moment of its introduction into the boiler that it requires to be heated. Besides, the use of the injector limits at the present time this previous heating of the water in the tender. Instead of 212° which was often reached, 95° and 104° at most cannot be exceeded. This is not to be neglected, far from it, especially in winter; but far better results would be obtained by making use of the hot gases and not of the steam; of the water forced back, and not the water stored in the tender.

SUPPLEMENT

TO THE SECOND AND THIRD VOLUME.

PRELIMINARY OBSERVATIONS

As the enumerative title of this work indicates, it does not include the study of all the questions connected with rolling-stock and the working of railways; two great divisions have been left out; signals (as we have already stated: III, 286) and stations.

The subjects treated of are those constituting essentially the ordinary duties of engineers; the subjects omitted have been so either from their very importance, from the length which their full investigation would have occupied, or on account of their special character, from the particular studies which they require beyond the proper province of the engineer.

Very simple in the beginning, signals have necessarily become remarkably complicated, in order to reconcile the requirements of safety with those of the traffic, and of the ever increasing speed of the trains. The *block-system*, the locking of the distant signal levers and of the points, the working of these latter at a distance (I, 272) have commenced to be introduced into France, and will certainly be more fully developed. But it is chiefly in England that the problem presents itself in all its complication; the extreme activity of the traffic there leads to the adoption of arrangements altogether novel, which would not be always necessary, nor even always applicable, but of which the explanation and discussion are at the present day quite inseparable from the general study of signals. Such as they are, the systems the most perfect in appearance, the *block-system* itself, applied at the same time under two different forms, are subject to reserve. Chances of accident, which might almost have been neglected formerly, acquire, under the actual conditions of working of the principal

English lines, a degree of real weight, and the improvement of measures of safety has not followed in as rapid a proportion as the dangers arising from progress of the traffic and also from the system of working, multiplying perhaps beyond measure the number of trains.

The increasing importance of the electric telegraph, as a regulator of the spacing of the trains, demands, at the present time on the part of those who devote themselves to the study of signals, a profound knowledge of the application of one of the principal branches of physics. In France, milder working conditions, so to say, have hitherto permitted safety to be guaranteed in a very satisfactory manner (for nowhere are collisions more rare) by relatively simple systems of signals. However, on the most crowded portions of some great lines, such as the Northern and the Mediterranean, new necessities have arisen. The *block-system*, the concentration of the working of the signals and points in look-out houses, and working at a distance, have received applications, which will soon be multiplied.

The automatic action of the trains, either to protect their rear or to make stoppage signals in front, has been and is still tried under new forms. In a word the *science* of signals, a science being created, and which for so long a period has been regarded only as an accessory, acquires every day greater importance, and consequently, a more pronounced speciality (*).

What we have just said with reference to signals, applies equally to stations, to goods-stations especially.

Engineers of talent have been known to fail completely in the establishing of stations, and thereby causing difficulties and expenses in the working, from which it could not be relieved excepting by very costly alterations. Here again, in effect, it is a question of special knowledge, and the engineer should be assisted by a traffic manager, experienced in questions of commercial traffic. It is no longer a question of absolute principle, since in order to discern the solution most appropriate to local conditions, great experience of traffic is required. Similarly, in order to deal usefully with the question of station arrangements, it would be necessary to proceed, by the study of numerous examples, in order to point out the faults committed, and to show how they could have been avoided.

Such a work would have required an amount of space exceeding the limits

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(*) M. *Barry's* little work, *Railway appliances*, published by *Longmans* (1 vol. 12mo, 1876), gives a substantial and instructive although elementary description of the actual state of the question in England.

L'*Étude* published in 1867, by M. *Brame*, engineer-in-chief of the corps of the *Ponts et Chaussées*, gives a very complete description of ordinary signals.

and the especially technical and scientific character of this book. Let us add (and this motive would alone be sufficient) that the author's studies had not fitted him for this delicate task, and on this double account he had to refrain from attempting it.

One single observation then on the subject of stations, the arrangements of which should be made subservient to considerations of commercial traffic, that is to say with regard to goods-sheds.

During the crises in freight which recur periodically with us, complaints have generally arisen with regard to the insufficient quantity of low speed stock or goods-waggons.

But the evil does not consist in this. Save in some very rare cases, the rolling-stock is sufficient, but is badly utilized, and it is so on account of the insufficient accommodation for loading and unloading, that is to say of the arrangement of the sheds, and of a defective manner of working.

How many times, at the periods when commerce was suffering from the want of waggons, have we seen intelligent station-masters and inspectors refuse to receive empty waggons which would only have increased the inextricable state of block of their already overcrowded stations!

Is it stock chiefly which is wanting when we see at the same station loaded waggons waiting whole weeks to be unloaded, while a few yards off goods are piled on the platforms and waiting to be loaded? The evil is the insufficiency of lines, which renders the platforms inaccessible, blocking and thus rendering immovable the rolling-stock, at the very time when its activity would be most necessary.

The want of mechanical means, the slowness of the operations spread over too great a surface, in one word, the small power of discharge per unit of surface of our goods-sheds : these are the real faults te be overcome, not only during periods when the difficulties of the situation are most felt and disorganize the staff, but even on ordinary occasions.

Use should be made of the rolling-stock which passes so great a part of its time in blocking up the lines. But, in order to arrive at this, the arrangement of the shed itself, must first of all be radically altered. Let us add, at the same time, that the principle of the mechanical appliances should not be adopted, nor the system chosen, until after scrupulous examination. The services rendered by these in England are very important, but are sometimes overdone. Notwithstanding the advantages presented in general by the concentration of the motive power, a division of it may be preferable in certain cases. All depends on the conditions of traffic which are so variable that we cannot but coïncide on this point with the reserves made

by M. *Sartiaux*, engineer of the *Ponts et Chaussées* and attached to the working of the Northern of France (*).

The extreme complication of the currents of traffic which cross in all directions, on a great system of lines, and require frequent exchanges of waggons between the trains, has given rise to difficulties which were not even thought of at the outset, and which tend to increase greatly the time lost by the rolling-stock.

The decomposition of the trains, the sorting of the waggons according to destinations, and the recomposition of the trains, constitute, with the loading and unloading of the vehicles, the actual work of a goods-shed. The first category of operations often requires a great number of sidings, and consequently a great extent of ground, which it would be frequently very difficult, and at times impossible to find near the shed itself.

The operations in question have thus become concentrated in a special station, placed for example near a junction, and bearing the name of the marshalling yard.

A shed properly so called, which is not provided with such a station, is often a marshalling yard or sorting-shed at the same time. The reciprocal is not the case. The sorting-shed is a sort of great *Shop of mechanical preparation*, the work of which chiefly consists in *classing* according to destinations; it is formed essentially of groups of lines, connected with each other and with the main lines, and on which the operations are effected by horses, turntables, fixed windlasses, steam-travellers, *Exter's* machines, etc.

The operations are greatly facilitated by giving the lines a suitable inclination which allows of working by gravitation; the sorting-sheds become then, as we have already said (II, 272), a further argument in favour of the application of a simple lever-brake to every goods-waggon.

This is enough to show those who have not had the opportunity of forming decided views on this subject, how important, how difficult, and above all, how *special* is the question of stations.

The considerations which precede were not however, the sole grounds for the two hiatus presented by this work. It appeared, at the commencement,

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(*) *Annales des Ponts et Chaussées*, April 1876, p. 205, etc.

M. de *Coëne*, engineer on the Western of France, has made on this important subject some very just observations and they may be recommended to the attention of the companies (*a*). The *Société des ingénieurs civils* (*Paris*) has however testified to the value of his work by a recompense well deserved.

(*a*) *Les chemins de fer en Angleterre.* Construction and working of good-sheds in large towns (*Autograph*, the 20th of June 1876).

advisable to reserve a sufficient space for a cursory view of the progress which the development of railways has imparted to the different branches of construction. From an engineering point of view, this subject, treated judiciously, comes more naturally within the scope of this work, than those which we have omitted.

Such is at least the opinion in which we have been confirmed by friendly advice.

But before considering this view of progress, which will conclude our work, we cannot refrain from adding a few words on some of the subjects dealt with so far.

Several years have elapsed since the publication of the first volume.

New facts have occurred: opinions have to be modified, errors corrected. Fortunate are those who can reperuse their own works at the end of ten years, and find them in perfect accord with facts, and even with themselves!

This is not the case, at any rate, in railway matters.

This eighth book will be then, a sort of review and conscientious revision.

It is divided into three chapters, each of which corresponds to one of the three volumes.

Each addition carries above it the number of the paragraph to which it refers. When it refers at the same time to several paragraphs not consecutive, the reference number is that of the paragraph to the subject of which it principally refers, and it is followed by other numbers placed between brackets. In this way, excessive subdivision of the additions is avoided, as also useless repetitions.

In the references made in the text, the number in Roman figures shows the volume, and the number in ordinary figures, the paragraph.

CHAPTER II.

No 21.

In England, third class carriages were for a long time instruments of torture. No air, no view, scarcely any room, not the shadow of a cushion. The position is greatly changed at the present time. The third class compartments are spacious, lighted by large glass windows, and often have cushions to the seats. The third class carriages of the London and North-Western are very comfortable, even for a long journey. They want nothing but curtains.

Between such thirds and the first, even luxuriously fitted, we ask if there really is room for a second class. This is the question which the Midland Company considered, and answered in the negative. The second class has disappeared. As the third class compartments are as spacious and nearly as comfortable as on the London and North-Western, it might be well said that it is not the second class which has been done away with, but the third; got up as it is, it becomes almost a second class at third class rates. It appears that the Midland Company has every reason to congratulate itself on the financial results of this reform and it is probable that the example will be followed by other companies.

It is already an important fact that commodious arrangements are offered to passengers at a low rate; but it is not the most considerable. The characteristic feature, I do not hesitate to say the *admirable* feature of the English railways, is the equality of fares without reference to speed. Almost all the trains, and all without exception on the Midland, contain third class carriages. The workman and the seaman travel in five hours the same as the millionaire, the 200 miles which separate *London* from *Liverpool;* and like the millionaire also, they have the choice of numerous daily trains, offered to them by several companies. While saving their money, they save their time equally with those of higher class.

What can be more truly democratic?

In France it takes the third class passenger 10 hours and 20 minutes to go from *Paris* to *Granville,* 204 miles; 10 hrs. 30 ms. from *Paris* to *Laval,* 187 miles; 10 hrs. 38 ms. from *Paris* to *Moulins,* 206 miles. The time is not very remote when it took third class passengers 4 hours 26 ms. to travel the 75 miles from *Paris* to *Orleans,* and the 85 miles from *Paris* to *Rouen.*

Certainly, all that is possible in England is not so in France, but the disproportion of the treatment is truly excessive. Some improvements have been recently introduced, chiefly in favour of second class passengers who are now admitted into trains from which they were formerly excluded : this is the thin end of the wedge. If, in France, express trains only admitting first class passengers are a necessity in certain directions and at certain periods of the year, that necessary concession should at least stop there. Every train having second class should also have third for those points where it stops. The speed allowed to third class passengers, *often excluded even from trains which contain carriages of that class*, is truly preposterous.

There above all, is reform most urgent; it is far more so than half an hour gained with difficulty on the run sufficiently quick, according to us, of our great expresses, from *Paris* to *Lyons*, to *Marseilles*, to *Bordeaux*, etc.

There is no doubt one objection : *change of classes*. The category of passengers in view, is not the only one to profit by the progress; but what does it matter? Is it thought, for example, that in England passengers capable of paying for first class, make any scruple in taking the third? By no means.

In all positions of fortune and in all countries, people are found susceptible to the attractions of cheapness. But the companies do not lose by that, because cheapness, — in this case the cheapness of speed, — produces its ordinary effect; it increases the consumption. In France, although in a less proportion no doubt, cheap speed would have the same effect. It is time to think of this and follow the English in this path of sound democracy, as far as the difference in the conditions allows. It is a necessary and without doubt definitive consequence of the actual political regime.

It is needless to say that the luxurious arrangements of the compartments, *Pullman* carriages, *Mann* carriages, etc., have been introduced on the English lines as on ours. This experiment seems to have decided the Midland Company on the great and massive carriages placed on two articulated trucks, which it considers more stable and safer at high speeds. It has just had several of these carriages constructed, according to the plan of M. *Clayton*, carriage and waggon superintendent. At first sight it seems singular that this consideration should lead to a return to American stock, which has always been objected to precisely, and not without reason, as being unsuitable for high speeds. But although the principle is the same, the application is modified in its details. Each truck, instead of being carried by only two axles close together, which enhances the amplitude of its oscillations, has six wheels, with a long base.

The same has already been done, as we have seen (II, 334, 336), for the engines.

The bodies, 53.41 feet long, are divided like those of the four-wheeled carriages, into first and third class compartments with side doors. The latter not allowing the body to be made as rigid as in the American stock, a solid bracing below gives the frame the necessary resistance.

Competition between the English railways. Since we have been led to glance at one of the most interesting points in the working of English railways, we shall continue this digression in order to notice a point which is at the same time intimately connected with it.

There is one means which occasionally succeeds in causing a false proposition to be accepted, and that is to enunciate it in absolute terms and to confer on it the name of axiom; and as axioms are not demonstrated, the necessity of proofs is thereby dispensed with.

Such is the pretended principle so often repeated in France, that competition between railways is impossible, and there scarcely fails to be added: "Look then at England."

The example is in truth well chosen.

If competition consists, as formerly, between undertakings by land and by water, in lowering the fares to the very utmost until failure results for those to whom the sinews of war fail, nothing of the sort is in fact possible for railways. A railway does not disappear. At the most, it may be absorbed by another one, and more than once this absorption was the origin and final object of the speculation. Once this object gained, the net product of the double transaction is pretty nearly summed up in an excess of charge imposed on the public funds, without real benefit to the general interest.

But if the competition consists in incessant efforts on the part of the whole of the producers to take a share in supplying the same market, in struggling against conditions relatively unfavourable, nowhere is it more lively, more alert, and let us add, more fruitful in advantages for the public, than between the English railways. For most destinations, the monopoly is combated with remarkable ardour, and several companies manage to divide the traffic.

"They arrange with each other," it is said in France. Happy arrangement, and it would be well if it were the same with us!

That has become very nearly impossible. The system of the great networks of lines has settled the question. We are indebted to it for a great number of lines, the utility of which was not very urgent, to judge by their

very small traffic, and by the absurdly small number of trains which disturb from time to time the silence of their solitudes (*).

Vested interests and treaties are inviolable; but because competition has been rendered nearly impossible in France, does it follow that it would be the same everywhere, independently of the system which has prevailed, and that railways would by their very nature escape the general and vital condition of all industries, competition!

To this there is only one reply, and that is also " look at England. "

This " understanding " which is alleged, what has it ended in? In the uniformity of rates? Perfectly; that is to say the companies which take the less direct routes take on themselves all the excess of distance; that they shrink at no sacrifice : execution, at great cost, of new lines procuring a reduction of a few miles of distance; the establishment of fast trains, etc., etc. It might be said that it is a struggle of pride more than of interests, and in fact this is probably the case.

It is known how moderate are the expectations of English companies in the matter of remuneration for the capital employed. For them competition has been a point of honour, and they accept, without grumbling, the burden which it involves for a traffic generally but little productive.

There are four different routes from *London* to *Manchester;* three to *Birmingham*, *Liverpool*, *Leeds*, *Edinburgh*, *Glasgow*, and *Perth;* two to *Sheffield*, *York*, etc.

If all the facilities given to the public are taken into account, in the shape of season-tickets, excursion-tickets at very reduced rates, which have received an enormous development, it will be found that the working of the English railways gives the public the most complete satisfaction; a result due for the most part to competition.

As this cannot be denied, the immense traffic on these lines is alleged as an explanation. Without doubt, but also what a network of lines!

We are, not moreover, making comparisons; we simply wished to correct an error, really too prevalent, above all as an unanswerable justification of the system of great networks of lines.

N° 40.

The idea of utilizing as much as possible the opening of the bridges, tunnels, and so on, is too sound to be a matter of indifferent with respect to the endeavours made, and the fresh progress in that direction.

For goods, there is, so to say, nothing to be done; the covered waggons

(*) It would be interesting, if this were the proper place, to value the cost of the unit of traffic on these lines, which are numerous.

approach as closely to the loading gauge as the simplicity of construction of the bodies, and the convenience and safety of the loading permit; and as to open trucks, the dimensions of their loads utilize the section, when its small specific weight allows, while for very heavy objects, the height is limited far below the gauge by the maximum load on the axles.

It is not the same thing for passenger-carriages. There has been no idea, as for covered waggons, of taking advantage of the available height. The bodies are made high enough for a tall man to stand upright in, without paying any attention to utilizing the rest of the space, which can only be done, however, by greatly reducing the width of the upper part of the body, which has to clear the overbridges with semi-circular arches, tunnels, and so on. The available portion in height can thus only be used in the shape of a distinct load on the top. This is what was at first done, as in road vehicles, by putting seats of reduced length.

A man standing up would soon be beyond the gauge, especially if he went from the centre line. A light roof, carried by slight pillars has for object, far less the shelter of the passengers than keeping them seated. But notwithstanding the strongest cautions, more than one imprudence has been dearly paid for.

The mode of access by means of steps fixed to the side of the body was inconvenient and even dangerous, particularly for getting down. A passenger coming out from below received at times on his head, the uncertain foot of a passenger from above.

The substitution of the end access for this side one, by means of a staircase, is a real, but incomplete improvement. In order to reach the place he has in view, the passenger has to follow the cornice, guiding himself by the hand rail fixed along side the roof. As to the small gallery along the cornice, it is less a safeguard than an increase of the danger: a false step being likely, on account of this arrangement, to end in a fall on the head instead of on the feet.

These carriages not having, under the roof, the minimum regulation height, could only run in virtue of a simple indulgence, and not by a regular authorization; but the most serious objection was the inconvenient and even perilous access to them. Such arrangements, admissible for active passengers with sang-froid, seem somewhat risky, when it is a question of people more or less excited (on holiday nights, especially) on a suburban line, such as the *Vincennes* one.

We are however, far from complaining of the Board for having in this circumstance departed somewhat from its habitual prudence, which is

sometimes considered to be carried too far. Whether the special protection attributed by the proverb, to those who exceed the limits of temperance, go for anything in the matter, accidents occurring to the upper story passengers have always been very rare. If a contrary opinion is entertained, it is for want of considering the enormous amount of the movement. This rarity proves that the public, even indifferently seated, knows pretty well how to protect itself.

It is not less true that the arrangement of carriages with open upper story, very low roof, and with access by lateral platforms, is a defective solution. It was quite right to admit it, so long as there were no others; it would be wrong to persist in it, in the face of what is due to M. *Vidard's* investigations.

For suburban trains, the use of imperials is a necessity. It allows enormous masses to be carried, without increase in the parliamentary numbers of vehicles, an advantage not to be despised, and which should tend to generalize the application of the principle since it greatly improves the ratio of the dead weight to the useful load.

Setting aside the risks which must neither be exaggerated nor denied, the ordinary carriage with upper seat, is only admissible for short daylight journeys. In spite of the two end screens, the passengers are not protected either against the rain or the sun, or against the wind particularly; thus they are seen to make for the seats against the front screen; and often, even during running, those who were late hasten with hazardous precipitation to secure a place on that privileged seat, as soon as they see it vacant.

In his first type (II, Pl. VII, *figs.* 4 to 7), M. *Vidard* had succeeded in getting rid of these dangers and drawbacks.

He raised the roof, suppressed the two side platforms, which he replaced by a centre passage, and closed in the outside of the upper story by panels and movable windows. These results could only be effected by lowering the body. As the diameter of the wheels could not be lowered, nor the level of the couplings altered, the problem was solved by a double bend of the iron-frame.

The lowering of the body has at the same time two positive advantages: 1st, it facilitates the access to the lower story, the floor of which came near the level of the low platforms; 2nd, it lowers the centre of gravity and improves the stability of the carriage.

The objection deduced from an excess of height of the centre of gravity for certain modes of distribution of the useful load between the two stories, has been moreover settled by practice. Carriages with closed upper stories

have at present run only by way of experiment in fast trains, but carriages with open upper stories have run for several months on the express trains of the two lines to *Versailles*, the regular speed of which is fixed at 37 miles an hour, which corresponds to an actual speed frequently reaching at least 43.5 miles an hour. With the couplings duly screwed up, these carriages run very steadily, even at the tail of the trains. It would doubtless be the same for those with closed upper stories, the centre of which, empty, is notably lower (4.10 feet instead of 4.75 feet). For ordinary second class carriages, this height is : 4.09 feet. Instead of, *without doubt*, it is, *a fortiori* that might be said, if the ratio of the wheel-base to the total length, between buffers were not less favourable in the second type. On account of the lowering of the body, into which the wheels are let, the wheel-base depends on the interior arrangements, the axles having to be in the plane of the diaphragms.

New type. (Pl. XVIII, *figs.* 1 to 4.) It will be seen that M. *Vidard's* solution definitively amounts to placing an *American* body on the top of the ordinary body with compartments. There was only one step to make in order to give to the upper story, the advantage which is claimed, not without reason, as the essential property, the real grounds for the American type, that is to say the communication throughout the whole extent of the train.

In order to carry out this idea, it was necessary to contrive a further lowering of the body, in order to increase the height of the longitudinal passage. M. *Vidard* has succeeded, by means of some details of construction, particularly by putting the springs below the axle-boxes. The floor of the lower story is no more than 2.21 feet above the rails, and 1.26 to 1.31 feet above the platforms, which allows the compartments to be entered without stepping up. Thus a footboard has only been kept with a view of trains being longer than the platforms. The clear height has been brought up to 5.58 feet below, and above to 5.91 feet, which allows free movement in the passage. These dimensions apply to the most restricted gauge, that resulting from the schedules of the concessions granted up to 1859. The breadth of the lower body, carried to 9.44 feet, leaves at the crossings, with the ordinary middle space, a clearance of 1.72 feet, which is sufficient for an open door to pass.

(As to the carriages with open upper story, the body of which has not been lowered, they go beyond the gauges of the old lines; the upper stories have thus to be removed when they are run on those lines. Their admission on to trains of suburban lines, has only been possible by the alteration

of the overworks, some of which, by the way, expose the drivers to serious risks.)

At the same time the glazed openings of the upper story have been enlarged, 2.62 feet high by 2 feet broad; an arrangement much more agreeable for the passengers. Further, the lowering of the support of the glass openings allows those who are on the platform looking for places, to see where there are any vacant, so as not to mount without being sure of a seat; needless to say that this investigation is easier still for the lower story, while in the case of ordinary carriages, it is necessary to get up on the step.

Let us add, which is not quite an indifferent matter, that these modifications improve the appearance of the carriage.

The establishment of a communication from one carriage to another, fulfils every necessary condition of safety and convenience. It is a little drawbridge *pp*, connected with the doors $\overline{\omega}\,\overline{\omega}$, and lowering at the same time that these latter are placed parallel to the axis of the train to form a handrail (Pl. XVIII, *fig.* 3).

This superposition of the two types of rolling-stock, which may be said to be opposed, would present, in view of their application to long journeys, advantages which are doubtless not decisive, but which cannot be overlooked. The conductor and guards placed on the upper story can pass, during running, from one carriage to another. As to what concerns accidents to the stock, a spring or an axle breaking, partly getting off the line, etc., the communication is sufficient, although restricted to the upper story. The passengers on the upper story, as well as those on the lower story, would be warned better on account of the greater amount of oscillation; they would then apply to the guard, who himself would inform the driver.

It is easy, on the other hand, to devote a portion of the upper story to arrangements of common interest, such as W.-C., dressing-closet, and even small refreshment bars. This latter innovation, provided the prices were moderate, would be hailed by a numerous class of travellers. It would be less so, by the Boards perhaps, bound by their agreements with the contractors of the refreshment-rooms of the principal stations.

The advantage of making use of these arrangements when they liked, would be a sort of premium, for the upper story passengers. In order to complete the working out of the application of his system to the great lines, M. *Vidard* has prepared a project including those comforts which are at the

present time almost necessities; we shall not dwell on these details, of which *fig.* 2 gives a sufficient idea.

M. *Vidard* appears to us to have solved in a satisfactory manner one economical question, the reduction of the dead weight; and a question of safety, the establishment in the trains of a communication, incomplete, but sufficient for the most serious contingencies.

It is besides necessary to proceed by degrees. It is for suburban lines, and for secondary lines with steep gradients, that the two-storied carriage is especially suited. It is not without surprise that one sees each of the three rates of the tariff represented by a Northern of France ordinary carriage, on the small branch from *Enghien* to *Montmorency*, on a gradient of one in 22, while one single two-storied carriage would most frequently be sufficient.

We shall dwell on some other attempts made with the view of establishing a communication throughout the train. On the line from *Longpré* to *Tréport*, for example, the passage is established laterally, and sheltered by the continuation of the roof. This external passage may in certain respects be preferable to the central passage, but it suppresses one place on each side. We have seen (II, 19) M. *Leprovost's* failure: he endeavoured to obviate that result of the inexorable gauge; by utilizing the waste space, M. *Vidard* obtains at once the communication and the reduction of the *dead weight*. On the *Tréport* line, the one is only obtained by increasing the other, a result in opposition to the principles which ought to prevail, especially on secondary lines, for which strict economy is a condition of existence.

By insisting besides on the grounds which recommend carriages with closed upper story, it must be admitted that the question is complex. If this type greatly reduces the *relative* dead weight of the full carriage, it increases the *absolute* dead weight. This consideration may prove serious on secondary lines with heavy gradients, without a level piece at stations, and provided with only a very limited staff. Light, handy carriages, are then preferable to heavy ones from the point of view of hand-shunting.

No 50 (and succeeding).

Heating carriages. This important and difficult problem, has not ceased to be studied in Germany, on several lines, and especially in France, where it has been the object of a very complete experimental investigation, on the part of the Eastern Company.

The heating of vehicles of all classes is now regarded as a necessity,

which tends to exclude the simple hot water cases, with the water at 194°, a solution too complicated, too inconvenient for the passengers, and too expensive for general use.

We may at once say however, that it is that which the companies seem to decide on, for want of better.

It has received, as must be admitted, an improvement of a certain importance. To restore the lost heat to the ordinary foot-warmers, the only way has been hitherto, to empty them, and refill them with hot water. This double operation which required to be performed every two or three hours, has become unnecessary. It is the same water, which again brought up to the initial temperature, by a rather expeditious means : on the *Orléans* lines, and on the Western of France, by an injection of high pressure steam; on the Eastern, by an ingenious plan which consists in leaving the warmers plunged, in water at 212° during the necessary time, about five minutes. A double noria, of which each pair of links supports one warmer, keeps them immersed in a well filled with boiling water; it has thus been possible by a current and industrial process, to replace the emptying and refilling of each of the elements.

But will that be sufficient to render the foot-warmer really practical, so as to render it applicable on the immense scale it has to act?

We doubt it. The preparatory operations are simplified, rendered more expeditious, certainly, but the most serious drawbacks remain.

The sand-warmers, worked from the outside, without opening the doors, only constitute an incomplete improvement. The sand having to be renewed about very four hours, the apparatus themselves must be changed, in the stations where the insufficiency of the stoppages does not allow of the sand being replaced. Hence, a great complication, and the necessity of maintaining a very considerable special stock. The warmers are difficult to handle also, on account of their high temperature at the beginning.

Steam, either from the exhaust, or directly from the boiler, or from a small special boiler set up in the van, seems to gain ground a little ; the second method has been tried on the Upper and Lower Silesian lines. The driver regulates the opening of the steam-cock so as to keep up, at the beginning of the steam-pipe, a pressure of abou 2 ats. A valve loaded accordingly, and placed under the foot-plate, ought always to blow-off a little steam (*).

Without dwelling on the details, every system which requires a channel

(*) See the instructions as to the use of this apparatus. *Handbuch für die spezielle, etc.*, t. IV, p. 525.

throughout the whole length of the train, appears to us inadmissible, from that circumstance alone; and if it is the steam which is made to circulate therein, the water deposited or condensed exposes the system to the difficulties arising from freezing.

The direct heating by stoves established in the bodies themselves, only applies to large spaces, and there is the disadvantage of a very unequal distribution of the heat. It could not be thought of, for carriages divided into small compartments.

A single stove, for each vehicle is thus adopted and placed outside, the heat being distributed by a circulation of water or of air.

The choice does not seem doubtful. If water at first seems to have the advantage, because, with equal mass and temperature, it stores up a greater quantity of heat than all other bodies, it has against it the slowness of heating, freezing, leaks, and so on. The air apparatus is more simple, more certain, more sensitive; it enters more promptly into action, and the absence of water in the circulation tubes is for an apparatus of intermittent service, a difficulty the less.

The *calorifère* has been the object of prolonged trials on the Eastern system; and as these trials have given satisfactory results, we shall describe no more of these apparatus.

Figs. 1 to 6, Pl. XXI, represents the apparatus applied to a third class carriage, with five compartments of ten places.

The stove or furnace P is suspended laterally from the side of one of the longitudinals. The hot air tube T, in sheet-iron $\frac{1}{25}$th of an inch thick, 6.30 inches in diameter, is surrounded by an envelope M 8 inches in diameter, leaving thus between the two envelopes a cushion of air of 0.79 of an inch.

This pipe communicates by means of a tube *t* with a warmer placed in the middle of each compartment: this is a sheet iron box, 7 inches wide and 9.8 feet long. The sheet is 1/25th of an inch, except on the upper surface, continuing the planking, where it is $\frac{2}{25}$ths.

On the side opposite the entrance of the air, each warmer has an opening placed under one of the seats, and provided with a key *k*, which allows the temperature to be regulated.

The products of combustion pass off into the chimney C, which rises a little above the roof. The fuel is fine coke, which is easily and quickly lighted at the first contact of inflammable material. It has often been a question, in Germany, of the adoption of prepared fuel, the slowness and

regularity of their combustion render very convenient to use. It appears, according to the trials made on the Eastern line, that small coke answers perfectly, and that there are no grounds for seeking any other fuel.

The application of a small furnace to every vehicle constitutes, in some people's opinion, a serious danger. It is not impossible in effect, that this circumstance might aggravate the consequences of a collision, or a running off the line. However, the mass in ignition is sufficiently small, so that these furnaces, especially fed with coke, may probably prove harmless in such cases.

It is only however after a more lengthened experience that it will be possible to pronounce definitively on the value of this mode of heating.

The preceding lines were written, when the Eastern Company sent us a copy of the report of M. *Regray*, engineer in chief, on the heating of carriages of all kinds (*). This report is a regular treatise on the subject. By the profound inquiry to which it was devoted into the state of the question in France and abroad, by the lengthened experiments in which it took the initiative and which it afterwards continued in virtue of a delegation from other companies, and by the publicity so complete which it gave to the results of these experiments, the Eastern of France has shown itself constant to the enlightened and progressive traditions, which are of old date. There could be no more triumphant reply to the reproach so often addressed to the companies, of being complacently immovable, of being hostile to the spirit of research and invention. Having immense resources available and a select staff, it is their duty to make use of these in the interest of progress. They understand this. We cannot here follow the report in its developments, notwithstanding the interest which they present; we must therefore confine ourselves to some short observations.

The conclusions deduced from so considerable a work have an incontestable authority; but as we cannot fully concur in the opinion of the company, we shall state in a few words the criticisms it seems to raise.

After a thorough comparative discussion, the report concludes thus (**):

" The programme is reduced to these simple terms: to warm the *feet* of the passengers, by means of hot water. "

During the cold season, *cold feet* are such a great discomfort to travellers, especially at night, that we should hardly think of contesting the utility of the foot-warmer. It has however its disadvantages, and the heating of

(*) *Le chauffage des voitures de toute classe sur les chemins de fer*, by M. *Regray*. 1 vol. 8vo with atlas, *Paris*, *Dunod*, 1876.

(**) Page 428.

the atmosphere, by heat apertures suitably arranged, which passengers can open and shut at their will, seems to us very likely to attain the object. This, however, is only a point of detail.

The preference given to hot water does not appear to us perfectly justified; we fear that the programme undertaken may create inextricable difficulties, and may end by compromising the solution of the problem, which has been and gone into however studied with a goodwill and resolution to which all credit is due.

The programme admits, as solution, the existing foot-warmer with hot water. As we have already said, it is that which at present prevails, in despair of anything better.

Even with the improvements pointed out, it would only be a very complicated, costly, and troublesome expedient, giving little satisfaction to passengers. For the Eastern of France lines only, not less than 18 000 foot-warmers would be required.

It must not be overlooked that once invested with the right by law, certain passengers would be found very exacting, and little inclined to recognize, by an exercise of good taste, all the trouble taken to insure their comfort. Thence, complaints, objurgations, and inevitable delays.

Heating by the circulation of hot water in channels with return of water and expansion-vase (*thermo-syphon*), has been investigated by the Eastern company, under the form given to it by MM. *Weibel* and *Briguet* of *Geneva* (*). The company has introduced successful alterations into this system (circulation in the foot-warmers in their places); but to the objection, capital according to our opinion, raised by the very presence of water, there is joined another, the necessity of lighting the fire long before the passengers take their places, or about two hours. So, in deciding on the application of this mode to a certain number of carriages, the company has admitted that the apparatus would remain constantly lighted, from the commencement to the end of the season. The company considers this continuity as the only efficacious means to oppose to freezing. It involves besides only a slight increase in the expenditure of the apparatus, which is already very costly; but above all, its maintenance is a serious matter. It will be, we fear, at the same time very troublesome and very dear.

Without being an advocate of heating by the heat stored up in sand, in earth, or generally in solid substances, it appears to us, however, preferable to the foot-warmer with hot water; the German system, which does away

(*) *Report*, p. 263.

with the opening of the doors for exchanging the warmers, deserves to be examined with a little more persistence.

It is urged in favour of water, that it possesses the property of storing up per unit of weight, and for the same rise of temperature, a great deal more heat than any other body. In the first place, it is from this very property that the great drawback results of the *slowness of starting* (mise en train). The argument would nevertheless be grounded if the elevation of temperature were the same. But it is limited to 212° at the very outside for water, because no effective pressure is admissible in the foot-warmer. It is not so with solids. Undoubtedly, the temperature is still limited, but much less so. By a series of envelopes with small conducting power and not affected by heat, in the middle of which the hot substance would be placed, the passage of the heat could be checked, and the exaggeration of temperature of the exterior surfaces prevented. Without doubt, by contrivances of this sort, the heat could be kept up longer, and the changings spread over much greater intervals than with foot-warmers at about 194°, the volume and weight of which could hardly be increased.

We expressed further back, the favourable opinion we have of *Mousseron's* system, resulting from the experiments made with such care on the Eastern of France.

This opinion has not been shaken by the contrary decision in the report.

The question of heating carriages of all classes being once propounded or rather imposed, it seemed to us that, in entering on this path so beset with difficulties, perfection should not be aimed at in the commencement.

Our programme was this:

Suppression of the whole concern of movable foot-warmers;

Exclusion of all channels running the whole length of the train;

Exclusion of water;

Easy and prompt starting.

Mousseron's system, as it left the hands of the Eastern, appeared and still appears to us to fulfil all these conditions in a satisfactory manner. Among other faults it is complained of, for not heating while standing, for requiring, like hot water, to be lighted two hours before the departure of the train, because of the slowness of the heating in carriages at rest (*). It would, doubtless be sufficient for lighting, and during long standing, to throw into the furnace some bits of easily inflammable material, wood for example,

(*) *Report*, p. 389.

to make up for the want of draught, and to keep up a brisk circulation during stoppages.

The report is, we fear, a little hard on the companies themselves, and a a little severe on the apparatus with circulation of hot air, investigated on Eastern with so much care and method.

The general arguments which the report opposes to the very principle of heating by the circulation of hot air, affect us little, we must avow. If these objections of principle were founded, they would apply to all cases, to simple apartments, to vast cathedrals, as well as to carriages. It is well known how extended is the use of hot air stoves, especially in hospitals. A mode of heating admitted to be irreproachable, when wards filled with sick are in question, can it be rejected, in the name of hygiene, for travellers who pass a few hours in a carriage?

What we fear altogether is, that in wishing to do too well, in rejecting a simple solution, relatively satisfactory, a serious embarrassment has been prepared for the companies, great expenses, and indifferent satisfaction of the public.

We believe that the long investigations of the Eastern Company might end in a more practical result.

We may mention on this subject an arrangement of detail applied by M. *Dietz*, and which, if it becomes general, will justly entitle him to the gratitude of the guard at the tail of the trains. The disk behind is placed in a niche made under the seat of the look-out, and isolated by a sheet of iron. The disk is a centre of heat powerful enough to be made use of, so long as it does not interfere with its action as a focus of light.

Nos 63 to 66.

The determination of the dimensions of longitudinals, supposed to have a constant cross section, presents no difficulty. They should be taken as beams loaded uniformly, placed on supports symmetrically situated on each side of the centre, and having necessarily two and two (the ends of the same spring) equal loads.

Let us consider only the bending moment in the middle of the longitudinal of a four-wheeled vehicle (Pl. XXI, *fig.* 12); the interposition of the springs between the longitudinal and the axles has no effect on this moment, at least in the most prevalent goods-stock, where there are no hangers, and consequently no strains resulting from their inclination.

l being the length of the longitudinal, p its load per unit of length, the load on each end of the springs is $\frac{pl}{4}$.

We have then, being the bending moment in M :

$$\mu = \frac{pl^2}{8} - \frac{pl}{4} \times \mathrm{M'M} - \frac{pl}{4} \times \mathrm{N'M} = \frac{pl^2}{8} - \frac{pl}{2}\left(\frac{\mathrm{M'M} + \mathrm{N'M}}{2}\right) = \frac{pl^2}{8} - \frac{pl}{4} \times \mathrm{MO} = \frac{pl}{8}(l - d),$$

d being the distance of the axles.

This value is independent of the length of the spring; and that has therefore no influence on the work of the longitudinal in the middle : the overhanging portion is calculated to start from the axle o, and not, as is sometimes thought, from the end M of the spring.

The tendency of the longitudinal to become convex upwards, is in no way modified by the springs which, by their inclination, follow the deformation of the longitudinals (*fig.* 12).

Every thing else equal, the moment pl only depends on d. It increases when d decreases and would reach its maximum for $d = 0$, that is to say, if the two axles converged into a single one; it is nought for $d = \frac{l}{r}$, that is to say for a value $\frac{1}{4}$th of the overhanging portion. There are then at the middle M, neither longitudinal nor shearing strains; the two halves of the longitudinal exert no action on each other, and we have, λ being the length of the spring :

1st, in O, $$\mu = \frac{pl}{4} \times \frac{l}{8} - \frac{pl}{4} \times \frac{\lambda}{2} = \frac{pl}{32}(l - 4\lambda);$$

2nd, in M′ (and in N′, everything being symmetrical relatively to O, since $\mu = o$),

$$\mu = \frac{p}{2}\left(\frac{l}{4} - \frac{\lambda}{2}\right)^2 = \frac{p}{32}(l^2 - 4\lambda l + 4\lambda^2),$$

a value which exceeds the preceding of $\frac{1}{8}p\lambda^2$; the greatest strain therefore takes place at the extremities of the spring.

μ' and μ'' unite as is evident, for $\lambda = 0$

$$\text{For } \lambda = \frac{l}{4}, \quad \mu' = 0, \text{ and } \mu'' = \frac{pl^2}{128};$$

For $\lambda = \frac{1}{2}$, $\mu'' = 0$; which is evident, the spring extending in that case to the extremities of the half longitudinal, from A to M.

In order to treat the question completely, we should only have to put, for the three lengths into which the half longitudinal is decomposed, the equations of the moments, and to treat them according to the general method. This is a piece of calculation too easy to require us to dwell on it.

We shall only say one word as to an analogous question, a very simple one too, when there are no bearing springs; that of the distribution of the axles, the most favourable to a given longitudinal, confining ourselves to the case of two axles, and always presuming the load uniformly spread over (Pl. XXI, *fig.* 13). The *maxima* of the moments corresponding to the two axles, and at the middle of the interval between them d. The most favourable value of that interval is that which renders these three *maxima* equal. This value is : $d = \frac{l\sqrt{2}}{1+\sqrt{2}} = 0.586\, l$; that of the three *maxima* $\frac{1}{16}\, p\, d^2 = 0.021\, p\, l^2$, and the overhanging portion $\frac{l-d}{2} = 0.2071\, l$.

No 64.

The substitution of iron for wood involved no modification at first in the general plan of the frames (Example, II, Pl. VIII, *fig.* 3), but at the present time, the cross diagonals are being done away with; the weight saved is, it is true, inconsiderable, but useless. The decomposition into triangles is no longer necessary, in effect, in order to insure the invariability of form of the rectangle; simple plate-iron gusset-pieces placed at the four angles, attain the object better, and more simply.

It is in this way that the iron frames of the Eastern of France carriages are now constructed.

At the same time, the drawing and buffing springs are brought from the middle portion to the ends, which greatly reduces the length of the draw-bars as well as of the buffer-rods. It is true that this subjects the whole length of the frame to the strains of buffing and drawing; but experience proves that, constituted as it is, it does not suffer appreciably.

No 73.

The isolation of the floor of the body-frame allowing of the free circulation of the air, may be favourable to the preservation of the wood; an advantage which would at the same time lose much of its value, seeing that it would no longer apply, excepting to the planking, on account of the substitution of iron for wood in the frames.

No 81.

In the state of rest, the *body* of an axle loaded on outside journals takes the circular form.

It is not without utility to remark, that in this position the body is subject

to no sliding strain, neither normally to the axis (*shearing* strain), nor along the direction of the fibres.

1st. The absence of the *shearing* strain is evident, the two forces applied to each half of the axle : the one, the load, on the journal; the other, the reaction of the nave, on the portion within the nave, forming a couple.

2nd. At each point, there is equality between the shearing strain, and the longitudinal sliding strain; the first being *nil*, the second is nil also.

The cause of this nullity of the sliding strain is easy to understand. If that strain is developed in general in a solid bent transversally, it is because of the inequality of traction (or compression) strains, applied to the two bases of a bundle of fibres limited by two surfaces parallel to the neutral layer, and by the lateral surfaces of the solid. With the circular form the effort referred to the unit of surface R, or $E\frac{v}{\rho}$ is constant, seeing that ρ is so, the fibres in question are thus in equilibrium on the action of the equal and contrary forces applied to its two bases, and therefore no sliding strain is developed in the surfaces which separate these fibres from the res of the solid.

Nos 92 and 124.

The key is in effect often done away with now, for example on the Eastern of France. The wheels getting loose, a most rare accident in carrying-stock, has not become more frequent, and perhaps this suppression has some effect in the rarity of the fractures of axles inside the nave (II, 85, and additions, vol. I, page 519).

No 196.

It is known that M. *Haswell*, of *Vienna*, has made an excellent use of the hydraulic press for forging parts of machinery in iron. The substitution of the continuous action of the press for the shocks, in some measure instantaneous, of the hammer, seems to have, at least in certain cases, positive advantages.

MM. *Brunon* frères, of *Rive-de-Gier*, apply the same principle. They manufacture in this way, buffers, dead buffers, racks on *Agudio's* system (*),

(*) Let us remark in passing, that the rack, formed of a ribbon folded back over and over, applies not only to the double horizontal toothing of M. *Agudio*, but also by simply reversing it to 90°, to the simple vertical toothing. There is no essential difference except as regards the means o fixing the central longitudinal

autoclaves for locomotive-boilers, etc.; but it is principally for the manufacture of waggon-wheels, that hydraulic forging receives in MM. *Brunon's* hands a most extended application.

The weight of these *centres*, all of the spoke type (Pl. XXI, *fig.* 14) varies from 271 lbs to 370, according to the thicknesses prescribed for the nave, spokes, and rim.

The diameter, variable between 2.69 and 3.02 feet ought to have a certain influence; but the dimensions are taken too arbitrarily for there to be any constant relation between the weight and the diameter.

For example, the *centre* of the Mediterranean weighs 289 lbs for a diameter of 2.69 feet, while the *Orleans centre* weighs 282 lbs for 3.02 feet, and that of the Eastern 370 lbs for the same diameter.

No 108.

The shape of the cast-iron wheels made by *Ganz*, at Buda, has been recently modified. The double disk (II, Pl. XII, *figs.* 26 and 27) has been given up (and the manufacture also simplified by the suppression of the nave), in order to approximate to the shape of the *Bochum* steel wheel (*fig.* 23), adding flanges to the disk towards the periphery, as is done in America. The flaws, difficult to avoid at that part, have almost disappeared, it is asserted, thanks to a rapid movement of rotation given to the mould, a method already tried for cast-steel ingots.

Nos 125 and 126.

Common springs, of reduced length for traction. We remarked in these paragraphs that, for goods-waggons, an elastic apparatus is more indispensable for traction than for buffing; in passenger-stock, on the contrary, a long travel, useful for buffing, would often be objectionable for drawing, because of the extent of the recoil after stopping. Even with the common spring, acting both ways, with all its length, nothing is easier than to limit the amplitude of each of the travels, by stops acting, some against the ends of the spring, the others on its middle. But it is at present often preferred to limit for the traction the length of the active part of the spring; which comes to the same thing, as if a special spring short, thick, and consequently very stiff, were made use of for this purpose.

Thus in the iron-frames of the Eastern where the springs are all carried close to the end transoms, two stops applied against the latter, limit the flexion at the middle and stiffest part of the spring.

It is no longer by the longitudinals only that the effort of traction is transmitted, but also by the cross-pieces. The gusset-pieces, which attach them to the longitudinals, reduce, moreover, their effective bearing.

The same arrangement has been applied to M. *Vidard's* carriages (Pl. XVIII, *fig.* 4), in which carrying the great springs to the ends of the frame was the necessary consequence of the curved shape of the longitudinals.

The stops are replaced with advantage, by small *Brown's* springs, or *Belleville's b, b.*

No 126.

The fast train which has been running for some time between *Paris* and *Bordeaux* accomplishes the 860 miles in 9 hours and 10 minutes, between *Paris* and *la Bastide*, or 39 miles an hour average reduced speed.

At the higher speeds which this mean speed requires on so great a distance, broken by pretty long stoppages, the carriages run very steadily, thanks to the precaution taken of tightening up the couplings as much as possible. The length of the levers has been doubled, and they are screwed home by two men.

No 131.

M. Dietz's *coupling.* This engineer has just contrived and applied on the Eastern of France, an ingenious mode of doing away with the guard-chains, at the same time preserving guarantees equivalent, taken altogether, to those of the ordinary coupling.

We know that each draw-hook carries its strainer with two links. One only is put on, the other is a reserve.

M. *Dietz's* idea consists of putting the two strainers on together. The effort of traction is divided equally between them; if one of them breaks, the other acts as a guard; it replaces the guard-chains, but without the chances of breaking and of oblique traction to which the latter are exposed.

The carrying out (Pl. XVII, *fig.* 14) only involves a simple modification: each hook C is placed, no longer on the continuation of the coupling-bar, but at the end of a cranked lever COM, jointed at O on to the end of that bar. The two links being hooked, the coupling with pressure of the buffers is done by tightening up one of the strainers. If, during running, a breakage takes place on one side, the other strainer places itself along the axis (*fig.* 15), supporting alone the effort of traction, as under ordinary condi-

tions. The reduction of the normal effect to one half, would at the same time render the breakage of one of the strainers very unlikely.

The only drawback consists in the fact that the guard-chains establish a connection between the frames, a precarious one it is true, and subject to serious objections (II, 131), but at least altogether independent of the coupling-bars; while with M. *Dietz's* system, if one of the bars or one of the axes of the levers gives way, all connection disappears. It would thus be necessary to give these pieces dimensions large enough to avoid all danger of breaking. In spite of this inferiority, more apparent than real, we do not hesitate to give M. *Dietz's* coupling the preference over the ordinary coupling, with only one strainer in action, and lateral guard-chains.

No 173.

In this book, we have considered it a duty to quote the names of the engineers who have, in various respects, contributed to the progress of railways.

Perhaps we have put M. *Edmond Roy* too much into the shade as regards the application of radial axle-boxes; his patent dates as far back as the 26th of May 1856, while the English patent of Mr. *W. Bridges Adams* is dated 1863.

As to M. *Reiner*, it results from the examination made by M. *Claudel*, subdirector of the South Austrian works at Vienna, that he has taken no patent out in Austria for the boxes in question, so that the priority would legally be M. *Roy's*.

We have no objection to record the fact here, and thus to meet the desire of an engineer who has studied practically and with a great deal of perseverance, the problem of the circulation of railway vehicles through curves of small radius.

No 187.

The meaning of the sentence which ends the second paragraph of this No.:

"As the two end-axles and the transversal axis of the vehicle (whether there be an axle in the middle or not) must converge towards the centre of the curve, it is evidently *at the middle of the distance between the axle and the transverse axis of the vehicle that the pin ought to be placed*" has been altered by a mistake which the reader will very likely have put right for himself.

It is sufficient to glance over *figure* 11, Pl. XVII, in order to see that the

words in italics ought to be replaced by these : " *at the middle of the distance of the two neighbouring axles, the one fixed, the other movable.* "

Nos 249 and 253.

On the application of ballast to engines. Ballast applied in France in the circumstances which we have made known, is greatly made use of in the United States, for the ordinary type, that is to say for the engine with leading bogie-truck and with four wheels coupled : as it always has for object to increase the adhesion, that is to say to bring the centre of gravity of the suspended weight behind, it is applied similarly to the *Crampton* engines of the Northern and Eastern of France, that is to say under the form of a mass of cast-iron replacing the hind transom of the frame. On the Northern, the ballast behind is combined however, with an enormous nave in cast-iron, on the driving-wheels. The adherent weight is thus brought up to 14 tons.

No 269.

The value $x' = P\,\frac{l' + d}{l + 2l'}$ is evidently less than the limit of the load at A, which is $P\,\frac{l' + d}{l + l'}$; it is less equally than the limit $P\,\frac{l - d}{d}$, of the load of B, for this condition amounts to $d < \frac{l}{2}$, and that is always amply fulfilled.

No 280 (and following).

The coupling-cranks, in engines with inside cylinders and coupled wheels, are invariably placed at an angle of 180° to the axle-cranks (II, Pls. XXXI and XXXII, *fig.* 4). I only know of two exceptions : the *London and Brighton*, and the Western of France.

The engines which do the express work on the first line have inside cylinders, inside frames and four wheels coupled; the coupling-cranks are placed in the same position as the axle-cranks.

According to the explanations which M. *Stroudley* the locomotive engineer, has given me, the starting-point of this derogation from the usual practice is an observation which he has had several times occasion to make, and which goes back over a dozen years. In comparing engines with four coupled wheels, some with outside, and others with inside cyl-

inders, he ascertained that the axles-boxes take, after the same distance run, less play in the horn-plates, or knock less, in the first than in the second. Was this effect due to the direction of the coupling, concordant with that of the driving-crank in the first case, opposite in the second? This cannot be asserted, seeing that this difference was not the only one. To decide the question M. *Stroudley* had an engine built with inside cylinders, but with the coupling-cranks placed in the same direction as those of the driving machinery; the steadiness of that engine was excellent in every way. The arrangement in question was adopted in consequence, and has not ceased to be applied since.

" I have at this moment in the sheds" says Mr. *Stroudley*, " an express engine which has run 158 000 miles without liners in the boxes or any other means of taking up the play; *the marks of the tool are still perfectly visible on the face of the guides.* On the average, the engines run more than 60 000 miles without the wheels being lifted. "

The engines of the Brighton line do excellent work at high speeds, and all that can be objected to them is the necessity of a heavier counterbalance-weight.

Let us add at the same time that from the point of view of the intensity of the disturbing forces, they would certainly be under more favourable conditions than outside cylinder engines the coupling-cranks as can be made shorter than the driving-cranks, while equality is obligatory when the cylinders are outside.

But, to say truly, it is not in this direction that it would be expedient to give the two classes of cranks different lengths. One would rather increase the length of the outside cranks in order to reduce the effort they transmit.

The effects observed by Mr. *Stroudley* are easily explained. In a coupled engine, the driving-axle is subjected to the action of two distinct classes of forces: 1st, those which result directly from the effective pressure of the steam on the piston; 2nd, the forces of inertia of the masses animated with relative movements.

When the cylinders are inside, the forces of inertia of the coupling parts may be at will, either in the same direction as those of the driving machinery, or in a contrary direction. The counterbalance necessary in order to realize a determined intermediate state between *vertical* equilibrium and *horizontal* equilibrium, is much less in the second case than in the first, and it is for this motive that the *reverse* coupling is preferred to the *concordant*.

Keeping the notations of Nos. 280 and succeeding (II) we have ;

	MASS OF THE COUNTERBALANCE-WEIGHT, COUPLING BEING :		DIFFERENCES.
	reverse.	concordant.	
Horizontal equilibrium.	$m + B + P - 2m' - B'$	$m + B + P + m' + B'$	$3m' + 2B'$
Vertical do.	$m + B\frac{\lambda}{b} - 2m' - B'$	$m + B\frac{\lambda}{b} + m' + B'$	$3m' + 2B'$
Differences.....	$B\left(1 - \frac{\lambda}{b}\right) + P$	$B\left(1 - \frac{\lambda}{b}\right) + P$	

But, with inverse coupling, another effect is neglected, which may acquire enough weight for it to be preferable to be avoided at the cost of an increase, even considerable, of the counterbalance-weight.

Then, in effect, the effort of the coupling-rod is added, on the driving-axle, to that of the connecting-rod, while with concordant coupling, the axle is only submitted to the difference of the two efforts: it is the same then with the journals.

Effects similar to those which struck Mr. *Stroudley*, although under a somewhat different form, have been remarked on the Western of France. It is the ovalization of the journals of the driving-axle, which chiefly attracted the attention of the engineers, and the small diameter or the maxima of wear corresponded naturally to the dead points.

Like Mr. *Stroudley*, and a little time after him, M. *Mayer*, engineer in-chief, sought the remedy in the concordance of the coupling. It has been applied to several engines with four wheels coupled, and with an equally satisfactory result.

Very solid, very durable, in the beginning, the cranked axle had become a fragile piece, certain to be fractured before the wear of the journals was appreciable. The latter thus required no attention.

At the present time the matter has assumed another aspect, they have succeeded on the Western, in greatly prolonging the durability of the cranked axles especially by adopting *Martin's* axle (II, Pl. XXXIII, *fig.* 4, which evidently admits only outside frames). The consideration of the wear of the journals, at first without interest, has then to be attended to ; it must be reduced, and that is arrived at by reversing the direction of the coupling.

The measure is not general, however ; this is because the nature of the tires has to be taken into account, to which the heavier counterbalance required by the concordant coupling gives an increase of periodical loads, and consequently of local wear, unless the vertical equilibrium is adhered

to pretty closely (II, 285). If the tires are not hard enough, it might be proper to keep to the inverse coupling. It is a sort of balance to make. But what is best to be done, for the tires as for the rails, is not to exceed the counterbalance of vertical equilibrium, which is sufficient, especially for actual engines, with great wheel-base, for steadiness in running.

The question raised and solved by Mr. *Stroudley* and M. *Mayer*, is interesting, and too much neglected, if not indeed often ignored. We cannot but call the attention of locomotive engineers to it. Inside cylinders are not in favour in France just now; the Northern comes back to them however, for high speed engines, and these have wheels large enough for the counterbalance-weights, even increased on account of the concordance of the coupling, to have but a small mass.

As to the indifference with which Mr. *Stroudley's* system seems to have met with in England where fast trains are almost always drawn by engines with inside cylinders and four coupled wheels, one might be surprised by it, were it not known how English engineers stick to their types, when they are satisfied with them. Without most certainly being enemies of progress, they are of those who willingly find that *the best is the enemy of the well.*

No 288.

In the United States, the driving-wheels, almost always of cast-iron (excepting the tires), seem often to have no counterbalance-weights. But it is that the builders have sought to utilize, in order to place them, the cavities made in the cast-iron in the rims and often in the spokes. It is clear that this means is only applicable to wheels of sufficient diameter to reduce to a trifle the counterbalance-weight, which has of course, lodged thus in the inside of the rim, the maximum leverage, provided it only occupies an arc of small extent.

No 292.

It is evident that the two arrangements (*figures* 12 and 13 Pl. XVII), equivalent for the distribution of the load over the axles, are not so for the strain on the longitudinals.

p being the load, supposed to be uniformly spread over the length per unit, π the load on each of the coupled wheels, d their distance apart, and s the length of the springs, the bending moment at the point M is in the first case $\frac{pl^2}{2}$, and in the second,

$$\frac{pl^2}{2} - \frac{\pi}{2} \times \mathrm{OM} = \frac{pl^2}{2} - \frac{\pi}{2}\left(\frac{s}{2} + \frac{d}{2}\right).$$

From the point of view of galloping movements, as for the strain on the longitudinal, the first arrangement is equivalent to one single axle placed to the right of M.

From the point of view of the zigzag movement, the same equivalence takes place, the sum of the movements of the transverse friction of the two pairs of wheels on the rails, relatively to the vertical axis passing through the centre of gravity of the engine, being the same for the two axles, and for the unique intermediate. The increase of the wheel-base due to the second axle is only apparent.

No other advantage must therefore be sought, in the application of the compensating-beam under this form, than that of bringing the load on two points instead of on one, and on two points always equally loaded.

As to arrangement 2, it reduces the work of the longitudinal at M, seeing that it has behind two points of support instead of one; but it changes nothing in the amplitude of the gallop or the zigzag. A difference in the distribution, like that which is produced with separate springs, can alone bring in a *resistance* additional to these movements, and that difference cannot be produced so long as the springs are connected by compensating-beams. The suppression of the overhanging portion is then more apparent than real.

The application of two beams on each side in engines with six wheels coupled, and of three in engines with eight wheels, is, we have stated, a fault (II, 292, p. 385). Useless, when the equation of condition which permits equality of the loads is satisfied, it becomes detrimental when this condition is not fulfilled. M. *Petroff*, professor at the Industrial School of St-Petersburg, has cited to me engines with eight wheels coupled of the Russian Company which have had three beams put on them, but with a slight modification. The longitudinal rests on these beams, not by simple pivots, but by supports having a small plane base of support. To an inclination of the beam corresponds in that case a slight displacement of the resting point of the support, and consequently a variation in the ratio of the leverages; which allows a fresh equilibrium to set up, ceasing, it is true, to realize equality (supposed however impossible in that case) of the loads on the axle. If this detail exerts, in effect, a favourable influence on the running of the engines to which it has been applied, it would deserve to be examined into closely.

This simple means of varying, within certain limits and automatically, the ratio of the leverages, is perhaps a useful corrective of the disadvantages complained of with respect to them.

No 319.

By an act dated the 3rd of May 1875, the United States Congress granted he funds necessary for the establishment and action of a commission charged with making methodical experiments on all metals used in construction, and particularly in the fixed and rolling-stock of railways. This commission has chosed Professor *R. Thurton* for secretary, to whom we are indebted for a remarkable apparatus for testing metals; it has appealed, by circular, to the experience of the great industrial establishments and the most competent men, and has divided itself into committees, corresponding to the principal applications of iron, such as rails, axles, and so on.

In Austria, several engineers and architects have worked out the bases of a similar institution, which would be extended to all materials of construction. They are endeavouring to obtain the financial cooperation of the government, who would not be the last to reap the points.

No 322.

Feed-troughs similar to those of the London and Northwestern are in action on the Central Pensylvania line; thanks to them, the *express* runs 131 miles in 3 hours and 27 minutes without stoppage.

No 328.

American Tenders. In spite of their being so much shorter than the carriages and the waggons, the double bogie-truck is applied to tenders.

These trucks are disposed like the leading trucks of locomotives, in all but two points: 1st, the journals are outside, while they are inside in the engines, in order to leave room for the cylinders, which are always outside; 2nd, the body is only supported in the front, by the centre of the truck. Behind, there are necessarily two supports, which are the middles of the two longitudinals. The body has thus the minimum number of points of support, that is to say three, as is the case with engines which have a leading bogie and two axles coupled, connected by lateral compensation-beams.

No 334.

Attention was long devoted in the United States, to reducing the diameter of the wheels of the bogie-truck of the engines, in order to bring its

parallel axles much closer together. The same principle was applied more strictly still to the carrying-stock, which is not subjected, like the engines, to the necessity of admitting a much greater wheel-base, that of the two invariable driving-axles.

But it was soon discovered that if the proximity of the axles of the truck facilitates its inscription in the curves, it is, beyond a certain limit, unfavourable to stability and resistance to movement. Every thing else equal, the amplitude of the oscillations of the truck round its turning pin, as well as the inclination of the vertical plane of the wheels on that of the rail, increase when the wheel-base diminishes. There is thus a limit to the closeness of the axles; in the United States, experience has led to the adoption of the gauge of the line, as the minimum distance between the axles.

If this rule holds good for trucks, the freedom of oscillation of which is complete, or only diminished by slight friction, on account of the concentration of the load on the middle region, it is not the same when this freedom is suitably regulated by inclined planes.

Moreover, in many American engines, the limit of about 6 feet results from the necessity of reserving, for the outside cylinders, a sufficient space, without unduly reducing the diameter of the wheels.

On lines with curves of large radius, the stability of the truck is obtained as we have seen, by combining a large wheel-base and the application of the load, not at the centre, but on the longitudinals (II, 335, Great Northern engines).

No 342.

Movable truck with single axle and central articulation of M. Novotny.

The Saxon system includes at the present day very irregular lines, the curves of which go down to 180 yards radius (line from *Zwickau* to *Schwarzenberg*), and exclude the six-wheeled coupled engines, while the gradients require the engines to work very near the limit of their adhesion.

Engines of the American type, with four wheels coupled and bogie-truck with two axles, run easily and safely through these lines, even at a speed of 38 miles, so long as the radius does not go below 250 yards.

In the sharper curves, and in spite of a correlative reduction of speed, instability appears.

Engines of sufficient power being able to be placed at the present time on four wheels only, without overloading the points of support, the solution of the problem was believed to be in that type, but it has been condemned

by experience. The fire-box overhanging and the relative insufficiency of the length of the wheel-base, give these engines a dangerous unsteadiness, even below the speed which they ought to attain on a horizontal (II, 246).

The trial of the engine with a *Bissel* truck and one axle, with inclined planes at the bearings of the principal frame on the truck, was then naturally indicated (see M. *Hartmann's* engine, vol. II, p. 452); but this type, with short wheel-base (11.72 feet), responded but imperfectly to the expectations of the directors of the Saxon lines. At a high speed, it wants stability, and in the sharp curves the wear of the flanges of the leading-truck is very rapid.

One of the most experienced engineers of the German railways, M. *Novotny*, counsellor at the General Direction at *Dresden*, took up the task of improving this state of affairs, and succeeded in so doing.

The solution, which dates from 1870, consists in placing the turning-pin to the right of the middle of the axle; it is then the limit of the American truck, the distance between the two axles becoming *nil*, and, up to a certain point also, the limit of the *Bissel* truck, the rod being taken equal to 0, in derogating from its principle (II, 339).

The effects of this modification are very marked; the running of the engine has become more regular, and smoother and the wear of the flanges of the leading-truck much slower, to the great advantage of the rails. The facts have been verified by a long series of observations, and M. *Novotny* has received one of the prizes instituted by the Union of German railways. 50 engines on the Saxon State lines (and 24 on other lines) have received the new arrangement.

In what consist the beneficial effects obtained by this displacement of the articulation?

The inventor, in applying it, was not guided by a preconceived idea. Even after so authentic a verification of the results, he declares straight forwardly " that neither he nor his friends have been able to succeed in forming the theory of an arrangement " of which the success is so complete (*).

In the face of this candour of M. *Novotny*, one would have to be very

(*) « In der angenehmen Hoffnung dass ich durch die beigefügten Zeichnungen Ihren mir so « werthen Wünschen entsprochen haben mochte, *bedauere ich dass es mir und meinen Freunden « noch nicht gelungen ist, eine Theorie dieser Construction welche sich in der Praxis so gut « bewahrt hat zu entwickeln.* » Extract from letter from M. *Novotny* to the author, dated March 20th 1876.

careful in hazarding a *theory*. But if it is only a matter (and we have no other object) of explaining the facts observed, independently of all numerical valuation, this explanation seems easy to us.

The object to attain, is, that the movable axle should be always placed normally to the line, or, in other terms, that the wheels should be always in the vertical plane of the element of the rail on which they rest. This position, the reactions of the outside rail on the flange of the wheel, would impart it to the axle, and if it did not take or keep it, the reason is, either that its geometrical connections oppose, or that the irregular movements of the engine, due chiefly to the inequalities of the permanent way, react on the axle.

The geometrical connections would only be a guarantee the more, if they did not end in rendering *necessary* the radial position of the axle. Such is in theory the effect of the *Bissel* joint. But if it insures that position when the longitudinal axis is directed exactly along the normal to the mean line of the two fixed axles, on the other hand, it renders it impossible, as long as that condition is not fulfilled.

Again (and this consideration is serious, especially for lines with a multiplicity of very sharp curves), when an engine enters a curve, the movable axle is engaged thereon, before the fixed axles, and their connection prevents the first from yielding to the action of the outside rail. The same incompatibility on leaving the curve. Irreproachable in theory, the *Bissel* connection only thus suits one determined position of the engine relatively to the line, a position from which it is constantly deviating.

There is then, from the point of view of the radial direction of the movable axle and the wear of the flanges, every advantage in replacing the *Bissel* connection by another which yields in that direction, *whatever may be the position taken by the axis of the frame within the possible limits of its oscillation.*

The joint placed to the right of the middle of the axle satisfies this condition.

The addition of inclined planes, which might, strictly speaking, be dispensed with in using *Bissel's* joint, becomes here quite indispensable.

Without them, the axle becomes too free and would obey, with equal facility, both the reactions of the outside rail which tend to give it the required position, and the causes which tend to make it deviate therefrom, that is to say the inequalities of the line, and the parasitical movements of the mass of the engine. A suitable inclination of the bearings creates a

resistance sufficient to neutralize very nearly, the influence of the causes of the second class, and the axle obeys almost exclusively the first.

This is not to say, however, that the *Bissel* joint has no standpoint; it is on the contrary indispensable when the extreme wheel-base exceeds a certain limit, relatively to the radius of the curves. The observation made (II, 334) on the subject of the American joint properly so called, applies equally to M. *Novotny's* joint, which is only a particular case of it.

It is then, once more, a question of wheel-base. When the length of this is small enough for the middle joint, necessarily placed on the axis of the frame, this method, according to reason and experience, is preferable to the *Bissel* truck.

M. *Novotny* has done for the convergence, what was done long since for the *longitudinal* play of the parallel axles. Formerly, the axles which received this play were conjugate : in *Baldwin's* engines (II, 332), by the longitudinal of a special truck; in M. *Beugniot's* (II, 332), by an oscillating rod. These connections have given place to arrangements applied individually to each of the axles to which this play is required to be given, and independently of the others. It is perfectly logical to apply the same principle, whenever the distance between the axles allows of it, to the convergent play; and the same organ, the inclined plane, regulates the use of this play, as well in the second case as in the first.

The details of execution, the drawings of which M. *Novotny* has been good enough to send me, are represented by *figures* 1 to 7, Pl. XX.

The general frame, inside, rests on the movable axle by the intermedium of the plates with inclined planes p, p and of a leading-bogie $t\,t$, suspended by the springs $r\,r$. Cheeks $e\,e$ limit the amplitude of the oscillation of the axle on each side of the turning-pin, while leaving it a little more play than is necessary for the stiffest curves. The pin A, a thick bolt 3.5 inches in diameter, is taken on one side by the struts f, f of the principal frame, and, on the other, by those of the bogie. The outside surface of the bearings $g\,g$ is either spherical (*figs* 1 and 2), or cylindrical (*figs* 4 and 5); the two arrangement act equally well.

The inclination of the bearings of the plates was at first fixed at $\frac{1}{8.5}$, and experience having shown that it could be increased without affecting the wear of the flanges, it was carried to $\frac{1}{5.5}$: the axle is then less susceptible to the irregularities of the road; the deviations which they impart to it on each side of the normal position reach at most 0.12 of an inch.

Figure 8 shows the comparative wear of the leading flanges for engines otherwise almost identical, some having the bogie fixed, the others with central turning-pin.

The full line refers to the tire when new; the heavy dotted one to the limit of wear in the region of the flange, requiring turning down; and the light dotted line, to the state observed at the end of the experiment.

1st. *Regatz engine;* leading-axle, fixed; wheel-base 12.47 feet. Line from *Chemnitz* to *Kimbach;* curves, 380 yards.

Distance run: 13,804; limit of wear nearly reached.

2nd. *Charleston;* leading-axle, movable; wheel-base 13 feet. Same line. Distance run: 22,837 miles; wear of the flanges, very slight.

3rd. *Breisach;* leading-axle, fixed. Line from *Chemnitz* to *Leipsic;* curves of 380 yards. Distance run: 16,369 miles; wear of the flanges, slight.

4th. *Albany;* leading-axle movable; wheel-base 13 feet. Line from *Chemnitz* to *Leipsic.*

Distance run: 9,518 miles; wear almost nothing on the flanges. Very short distance.

5th. *Jackson;* Leading-axle, movable. Line from *Chemnitz* to *Leipsic*, curves of 380 yards.

Distance run: 21,685 lines: wear of the flanges, very slight.

6th. *Annaberg;* Leading-axle, movable; wheel-base 11.72. Line from *Chemnitz* to *Annaberg;* curves of 185 yards.

Distance run: 19,508 miles; wear of the flanges, at the limit.

7th. *Komolan;* leading-axle, movable; wheel-base 11.72 feet. Same line.

Distance run; 7229 miles; wear of the flanges, scarcely anything, but the distance is very small.

8th. *Philadelphia;* leading-axle movable; wheel-base 11.72 feet. Same line.

Distance run: 12,947 miles; wear slight, especially on the left flange.

It is be regretted that these precise comparisons had not been extended to engines with *Bissel's* articulation, and to others having no convergent play in the leading-axle, but with longitudinal play (II, 332).

No 344.

In *W. Hudson's* engine (II, Pl. LXXXVI, *fig.* 8), the middle of the beam A O, the point of support of the front part of the boiler, is fixed. The extremity A, which rests on the middle of the cross-beam B has thus a horizontal movement equal and contrary to that which the extremity O takes when the bogie turns round the joint of its rod; the long rods by which the compensating-beam is suspended to the spring of the fixed axle, yield easily to that oscillation.

The firm of *Baldwin* often applies the *Bissel* truck under a form (Pl. XX, *figs* 9 to 11) analogous to the preceding on account of the presence of a

compensating-beam along the axis, but which, in reality, approximates rather o engines with *Bissel's* truck, constructed in Europe. The truck τ, τ movable round the turning-pin I, to which it is bound by the triangular rod *f*, *f*, receives in effect, its load directly from the frame which is continued over it; the cross-beam T rests on the cast-iron box P suspended by the rods, *b*, *b*, to the struts S, S, of the frame. On a curve, the axle, under the pressure of the rail, carries with it the truck τ, τ which turns round I. The struts S, S, themselves carry with them in this movement the small rods *b*, *b* which, retained at their extremities below by the supports *q*, *q*, of the fixed box P, take different inclinations to the vertical. From the unsymmetrical nature of these inclinations, results the tendency of the truck to come back to its mean position : it plays the same part as the inclined planes.

A bolt θ with a nut *e* prevents the frame leaving the bogie by rising.

So far, it is then the *Bissel* truck with one axle, such as we have described it (II, 342, 344); but this arrangement, especially with a long frame, would be defective, dangerous even, on many American roads; the distribution of the weight over the axles would undergo great disturbances. This drawback is avoided by connecting by a compensating-beam B B the suspension of the bogie with that of the first fixed axle. Such is the sole function of that beam; while in the preceding engine, it had at the same time the function of loading the bogie.

Baldwin's compensating-beam is placed under much better conditions than *Hudson's*. Supported like the latter behind, on the middle of a cross-beam *k*, it is let in, in the front, to a stirrup C, forming the continuation of the bolt θ which brings the load by means of the nut *e* and the india-rubber washer R on to the cross-beam T. This compensating-beam has thus no horizontal oscillation. The connection of the two axles together, the one fixed, the other movable, is thus effected by one single compensating-beam, oscillating in the plane of symmetry of the engine, and replacing the two side compensating-beams, become then impossible, which are applied to parallel axles. This is the interesting part of the arrangement.

No 346.

Radial boxes have been applied by *Building Company* of *Berlin* (the old *Schwartzkopf* company), to engines constructed for the *Berlin* and *Hamburg* line.

This engine with four wheels (leading) coupled and loaded by means of

compensating-beams, with outside cylinders and inside frame, have the third axle behind the fire-box, viz. the one which has the radial boxes. It is loaded by a cross-spring, to the ends of which the frame is suspended, and which is supported at its middle by a hemispherical support on a strut carrying at each end a steel roller resting on the axle-box. The surface of support of each roller is a horizontal cylinder of 8 inches radius, continued towards the outside by an inclined plane. On a curve, the outside roller rises on this inclined plane, while the inside one rises also, but much less, on the nearly horizontal elements of the cylindrical surface. The corresponding inclination of the strut creates for the system a tendency to come back to its mean position on leaving the curve, a tendency which results also from the oblique position, which has been taken relatively to the frame, by the axle and the strut guided by the slides of the axle-box, which belong to a vertical cylinder of 5.48 feet radius.

With the longitudinal play alone, one cross-spring convex upwards, with inclined planes at the two ends, would be enough. One would have to be thoroughly convinced of the necessity of the convergence to adopt the complicated arrangement just described.

No 358.

Since the publication of volume II, a locomotive of the type proposed by M. *Rarchaert* has been built and put into service.

Figures 5 and 6 (Pl. XVIII), taken from a description published by M. *Collignon* (*), represent its essential elements.

" The intermediate shaft ", says M. *Collignon*, " is on the level of the longitudinals, that is to say at an inch or so below the centres of driving-wheels ; that it is by a veritable *triangular connecting-rod* that it acts on the cranks of the neighbouring axles. The advantages of this arrangement will be understood. The intermediate axle may act in two ways on each of the adjacent axles : directly, by means of the straight rod which connects them ; indirectly, by means of the rod which drives the other driving-shaft, and by the connection between the crank of this second axle to the axle of the first. M. *Rarchaert's*, although it has only one connecting-rod, has thus no dead point, for whatever may be the position of this triangular connecting-rod, the crank of the driving-shaft cannot be at the same time on the continuation of the two rods which act on it, and one at least of which exerts its whole effect on it. "

The triangular connecting-rod has, most certainly, serious drawbacks, but they are much less than those to which the position of the three centres

(*) *Annales des Ponts et Chaussées*, 1873, Vol. V, p. 139, and *Annales des Mines*, 1873, vol. IV, p. 20.

in one line would produce. It appears that such was M. *Rarchaert's* first idea. If this is so, he has done wisely in our view, to give it up. At starting, especially, the cranks being at the dead points, the rectilinear connecting-rod would be subjected to efforts of transverse flexion, that is to say to abnormal conditions of work. The rods ought to work in longitudinal compression or traction, and not as solids placed on supports loaded at the centre. To this consideration, which would suffice, others of a more serious nature may be added, relative to the transmission itself, which can only be made evident by sketches on a large scale. This verification has been made by the engineers of the *Fives-Lille* Company, who wished fully to ascertain the degree of possibility of the mode of transmission by a central rod, rectilinear or triangular. For the first, the result was altogether negative. As to the triangular rod, the drawings brought out, in certain particular cases, particularly under the influence of the inequalities of the road, deformations of that piece, which can only be reduced by admitting between the organs of the machinery, play quite disproportionate, it seemed, to what experience permits in well constituted engines.

M. *Rarchaert's* engine has been at work, first on the line from *Fougères* to *Mont-Saint-Michel*, then on that from *Orleans* to *Châlons*. The first trial alone had any interest; the engine was in that case working under conditions in harmony with its principle, particularly on curves of small radius. The second period of trial (which lasted very shortly however), made on a line with curves of large radius, did not and could not lead to any positive conclusion regarding the system.

As to the first period (*), it displayed, from the beginning, serious and numerous faults, several of which were evident at once, but which it is useless to point out, for they affect only the motor system proper and in no way the mode of transmission, which alone was the question.

" In spite of all its imperfections, " says M. *Dornes*, the locomotive engineer, " this engine managed to do the same work as our six-wheeled coupled engines of the weight of about 30 tons under very good conditions.

" In spite of its complication of joints, it appeared in no way to strain in running, and gave rise to no trepidation arising from the reactions of the various organs one on the other. The zigzag and pitching were greatly reduced.

" After a service of more than 2500 miles, it was ascertained that the bearings of the central triangular connecting-rod had only an insignificant amount of wear, quite normal, and that this part appeared in no way to have been strained beyond the ordinary limits in the parts of locomotives. "

(*) M. *Massieu*, ingénieur en chef des Mines, has given an account of it in a very complete report, which has been published in the *Annales des Mines*.

Experience has not then, altogether, condemned the system itself. I proves, rather, that if the triangular connecting-rod does not constitute a geometrical mode of transmission, the amount of play necessary for reducing the consequences of this imperfection has not at least anything excessive either from the point of view of the running of the engine, or from the point of view of the preservation of the parts. That is something.

Unfortunately comparative results are especially required in such matters, and these results are wanting.

This engine with total adhesion and great flexibility, should have been compared with an engine having three axles coupled, not absolutely fixed, but having longitudinal play, which is now everywhere admitted.

If, with a total wheel-base naturally less and this simple longitudinal play, the engine with parallel axles acted from the point of view of the wear of the flanges and rails, nearly the same as the engine with central connecting-rod, the latter would be superfluous.

Such was the question, before the trials; such it is still, after them.

We are, for our part, an indifferent partisan of this arrangement, which is complicated, and geometrically imperfect. We have little faith in its future.

It must be admitted however that the *Fairlie* type is more complicated still, which has not prevented it from obtaining a certain success. Perhaps the other would be suitable for some extreme lines. M. *Rarchaert* has besides the merit of having proved, by his personal efforts, the possibility of applying the principle of the central triangular connecting-rod, a principle long known (II, 358) but which had not, hitherto, left the realms of pure speculation.

Nos **368** (and **422**).

The principles exposed in these two paragraphs have recently received a fresh confirmation.

The service of the little line from *Zürich* to the *Uetliberg*, where the rate of inclination goes up to one in 14.5, is done by locomotive with simple adhesion. Let us at once state that this limit is only reached for a length of half a mile and at the upper end of the line, so that the ascending movement is retarded on a portion of this piece.

The adhesion is sufficient; from which it may be immediately concluded that a relatively small useful load suffices, without endeavouring to increase it by a reduction of the speed.

The latter is, in effect, equal, superior indeed, to that which is admitted on several great lines for goods-trains. It is ten miles an hour, at least, that is to say on gradients of more than one in 16.6, and on curves of less than 200 yards radius.

The engine with six wheels coupled carrying its supplies, and weighing, empty, 19 tons, full, 24 to 25 tons, pushes easily, up to the rate of one in 16.6, three waggons weighing from 33 to 34 tons; and beyond, 2 waggons weighing 22 tons, or a little less than the weight of the engine.

The following are the principal elements of the engines, which were built by *Krauss :*

		sq. ft,	
Heating-surface	direct....	53.28	778.23 square feet.
	indirect..	724.95	

Maximum pressure : 12 ats.

Cylinders : 12.6 inches by 21.26 inches stroke.

Wheels : 2.98 feet in diameter.

Wheel-base : 6.56 feet, on account of the radius of the curves (minimum 150 feet). The frame is hung on three springs, two longitudinal common to the two hind axles, and one across at the leading-axle.

No 370.

This position, often intolerable, of the driver of the tail engine, has occurred on several occasions in the tunnel curve of *Piteccio* (line from *Bologna* to *Pistoia*). Notwithstanding its ventilating shafts, several cases of suffocation of the driver or the fireman have taken place. The double traction has been consequently suppressed, — a radical remedy, — but as troublesome for the working as it is unsatisfactory from the point of view of breakages of couplings, and running backwards.

At the Mount-Cenis tunnel, the workmen suffer sometimes from the accumulation of carbonic acid; a tube 8 inches in diameter extending from one end to the other is kept constantly filled with compressed air, and cocks placed at alternate distances allow the men to procure a jet of pure air at need.

An artificial ventilation is not yet necessary, but it would doubtless become so for an increase, even to a very moderate extent, of the existing traffic.

No 396.

Since the *Lyons* Company has begun to follow the rational determination of the loads of the engines, the other companies have not ceased to

pay attention to that important question. The gradual modification of the elements in presence necessitate from time to time, revisions of the rules relating to the loads, and to the allowance of fuel. We shall enter into some details on the results to which this rearrangement has arrived on the Eastern and Western systems.

Its object is to make a more thorough use of the engines, by modifying in consequence their allowances, and by equitably indemnifying the staff for the increase of work required from them, so that everybody gains.

1st, EASTERN.

The division of the lines of the system into 11 profile types (II, 396), is maintained, except the suppression of the type *d*, which has in fact disappeared. The essential modification consists in the creation of 10 train-types, to one of which a *real* train can always be referred in all the phases through which it passes during its journey.

These types are classed as follows, according to their normal speed (*):

CATEGORIES of the trains.	NORMAL SPEED.	REAL SPEED IN RUNNING according to the ratio of inclination of the profile.
Goods-trains.....	1st train-type... 12 miles an hour.	7.5 to 15.5 miles an hour.
	2nd do. ... 15 5 »	9 to 19 »
	3d do. ... 19 »	12.5 to 22 »
Mixed trains.....	4th do. ... 22 »	15.5 to 25 »
	5th do. ... 26 »	19 to 27 »
Ordinary passenger trains.....	6th do. ... 27 »	22 to 31 »
	7th do. ... 31 »	25 to 34 »
Direct express and mail trains.....	8th do. ... 34 »	27 to 37 »
	9th do ... 37 »	31 to 40 »
	10th do. ... 40 »	34 to 43 »

The variation of the running speed, within the limits assigned to each train-type, corresponds to the variation of the inclination which a train meets on the same profile (A, B.... I, K); in such a way that the lowest speed is employed to get over the steepest gradient of that profile; in consequence, each line of the system has been examined from the point of view of the variations of inclination, and the time of running to each train-type has been calculated from station to station, in the two directions.

These numbers are collected in a book bearing the name of *Livret des honoraires des trains-types.*

(*) Extract from the circular letter No 24 of the 20th of April 1875.

Each train carries, mentioned in the time-book, the indication of the *train* or *train-types* according to which its running has been made out.

Load of the engines. The composition of the passenger-trains is determined according to the requirements of the service.

That of the mixed trains and goods-trains is determined according to the power of the engines, and the profile of the line to be run over; at the same time, loads exceeding the power of the engine, and double traction are of course provided for and regulated.

The loads to be drawn have been calculated for each series of engines, each *train-type* and each *profile-type*. They form the book of engine-loads, expressed in units of 10-tons.

We reproduce, as example, an extract from these tables, comprising series I (single engines); series II (one of the series of engines with four wheels coupled); series V (one of the series with six wheels coupled); and series X, comprising the most powerful engines with eight wheels coupled.

The three first tables are calculated for the train-types 20 to 40, and the fourth, for the train-types 20 to 30 only; the normal speeds which exceed that limit are only applied to passenger-trains.

The last table includes all the profiles only, included, I and K, which do not figure on the others; the engines with eight wheels coupled running only for goods, on profiles with steep gradients.

EASTERN.

TABLE OF THE ENGINE-LOADS.

ACCORDING TO THE TRAINS-TYPES AND THE PROFILE-TYPES.

N. B. The figures in the column of *loads* give the *number* of units of load.

PROFILES	TRAIN TYPE 25.			TRAIN-TYPE 30.			TRAIN-TYPE 35.			TRAIN-TYPE 40.		
	LOADS.		Number maxim. of vehic.	LOADS.		Number maxim. of vehic.	LOADS.		Number maxim. of vehic.	LOADS.		Number maxim. of vehic.
	min.	max.		min.	max.		min.	max.		min.	max.	
SERIES I. — ENGINES 1 to 78 (single).												
A	26	34	34	22	29	34	20	25	34	18	20	34
B	23	29	29	20	24	29	18	10	29	16	18	29
C	20	25	28	17	20	28	15	17	28	14	15	28
D	17	22	25	15	18	25	13	15	25	12	13	25
E	14	20	25	12	16	25	11	13	25	10	11	22
F	11	17	24	10	14	24	9	11	22	8	9	18
G	9	15	24	8	12	24	7	9	18	6	7	14
H	8	13	22	7	10	20	6	8	16	5	6	12

N. B. On the *Provins* branch two single engines are at work, the maximum load of which is fixed at 12 units.

SERIES II. — ENGINES 91 to 100, 304 to 361, 189 to 222, 243 to 258 (4 w. coup.).												
A	28	37	37	24	32	37	22	28	37	20	22	37
B	24	32	32	22	25	32	20	23	32	17	19	32
C	21	27	30	19	22	30	18	21	30	15	17	30
D	18	24	27	16	20	27	15	17	27	13	15	27
E	15	21	26	13	18	26	12	15	26	11	13	26
F	12	18	25	11	16	25	10	13	25	9	11	22
G	10	16	25	9	13	25	8	10	20	7	8	16
H	9	14	23	7	11	22	6	9	18	5	7	14
I												
K												
. . . . .												

SERIES V. — ENGINES 0,1 to 0,32 (6 w. coup.).												
A	32	43	43	28	37	43	23	30	43	18	20	40
B	28	39	39	23	31	39	20	25	39	15	18	36
C	25	36	39	20	30	39	17	23	39	14	16	32
D	22	32	35	17	25	35	14	18	35	12	13	26
E	19	27	32	14	21	32	12	15	30	11	12	24
F	16	23	30	13	16	30	11	12	24	10	11	22
G	13	19	28	11	13	26	10	11	22	9	10	20
H	11	17	26	9	11	22	8	9	18	7	8	16
I												
K												
. . . . .												

SERIES X. — ENGINES 0,558 to 0,569 (8 w. coup.).												
A	64	75	75	60	75	75	56	64	75	»	»	»
B	59	72	72	56	72	72	48	56	72	»	»	»
C	56	68	71	53	68	71	42	51	71	»	»	»
D	53	63	63	47	60	63	36	46	63	»	»	»
E	45	55	57	40	52	57	31	41	57	»	»	»
F	37	47	51	32	44	51	25	34	51	»	»	»
G	30	40	48	27	39	48	20	29	48	»	»	»
H	25	36	44	23	35	44	16	23	44	»	»	»
I	20	28	37	18	26	37	12	19	37	»	»	»
K	18	23	33	16	22	33	10	17	33	»	»	»

To these examples it is desirable to add the following rules.

1st. The minimum load must be taken in all weathers.

The maximum load can never be exceeded.

The load of the trains is thus found always comprised between these maxima and minima, and is determined every day by the locomotive department.

2nd. In order to facilitate the working at certain points where there is an obstacle to get over, it has been decided that goods-trains and mixed trains shall be drawn by an auxiliary engine at the following places of the system. (The list follows.)

3rd. The load of a train drawn by two engines, one of which is an auxiliary engine, may be equal to the sum of the loads authorized for each of the two engines.

The number of vehicles in this case, has for limit the sum of the limits indicated for each of the two engines, without exceeding the number of 75 vehicles.

4th. The auxiliary engines *can* be coupled on to the tail of trains of any kind, in order to get over gradients. For all the trains of the types 20, 25, 30, the auxiliary engine *ought* to be coupled on behind.

5th. In no case should the speed of a train pushed exceed 15.5 miles an hour.

6th. When a second engine lighted is coupled to a train, its power may be utilized and the train considered as drawn in double traction.

When a train in double traction gets on to one of the *auxiliary* sections (N° 2) the second engine becomes the *auxiliary engine*.

If the power of the two engines is insufficient, the special engine of the incline ought to be coupled on behind; the two engines thus keep their places at the head of the train.

On gradients equal or superior to one in 100, the second engine may be coupled on behind. In that case the speed ought not to exceed 15.5 miles an hour.

7th. In the case of double traction, the limit of the load of the trains is fixed as follows, whatever may be the state of the weather:

On the profiles A to F, the sum of the minimum loads of each engine reduced by 5 units;

On the profiles G to K, the sum of the minimum loads of each engine.

At the same time, the loads of the trains in double traction, whatever may be their types, ought not to exceed the maximum loads fixed in the book for the series X, train-types 20, on the divers profiles. (See the above table.) This load may even be reduced, if the heads of the depôts fear for the couplings.

The number of vehicles of the trains in double traction cannot exceed one and a half the number belonging to the most powerful engine, as if it were drawing the train alone. This number can in no case exceed 75: it may even be reduced if the heads of the depôts fear for the couplings.

2nd, Western.

The loads of the trains of this system have been recently subjected to a fresh examination; which has resulted in a project containing important modifications. M. *Meyer*, the chief locomotive superintendent, has been good enough to give me notice of this, and I shall make some extracts from the document.

The system has been divided into eight categories, not only according to the profile

but also " according to the nature of the traffic which is produced more in one direction than the other, and taking into account the seasons during which the trains are loaded. ". The suburban lines, where the nearness of the stations creates particular conditions, and where the passenger-trains are composed of a special stock, forming a category apart.

Each line may in general belong to two categories, according to the direction run. For example, the line of *Pecq-St-Germain* belongs to the eighth category (which it alone constitutes) for the trains called ascending (starting from *Paris*) and to the first for the descending trains (from *St-Germain* to *Paris*); the line from *Clèves* to *Buchy* to the sixth; that from *Buchy* to *Clèves* to the first. Many lines belong in both directions to the same category, for example from *Paris* to *Rouen* (first).

Let us add that the divisions of one line into categories do not correspond exactly for the two directions of running, that line having to be divided into as many portions as it includes categories, and the number of the latter varying naturally in many cases with the direction in which the line is run over.

The loads are calculated for each train in proportion to its speed and to the category of the line over which it runs (a category which implies, as we have just seen, the direction of the running) and of the type of engine drawing it.

The two subjoined partial tables, relative to the highest and lowest speeds admitted on the great lines, will render the mechanism perfectly comprehensible, the mechanism of the general table regulating the *composition and load of the trains on the great lines.*

Composition and load of the trains of the great lines.

NATURE OF THE TRAINS and of the engines.	CATEGORY OF THE LINES.											
	No 1.		No 2.		No 3.		No 4.		No 5.		No 6.	
	from the 1st April to the 31st October.	from the 1st November to the 30th March.	from the 1st April to the 31st October.	from the 1st November to the 31st March.	from the 1st April to the 31st October.	from the 1st November to the 31st March.	from the 1st April to the 31st October.	from the 1st November to the 31st March.	from the 1st April to the 31st October.	from the 1st November to the 31st March.	from the 1st April to the 31st October.	from the 1st November to the 31st March.
1st. Trains running from 38 to 43 miles an hour (calculated speed slackening not included).												
101 to 138	10	9	9	8	8	7	7	6	6	5	6	5
141 to 150, 161 to 168	9	8	8	7	7	6	6	5	5	5	5	4
169 to 176	11	10	10	9	9	8	8	7	7	6	6	5
281 to 211	12	11	11	10	10	9	9	8	8	7	7	6
262 to 264, 266 to 273, 321 to 328	13	12	12	11	11	10	10	9	8	9	7	6
337 to 348	15	14	14	13	12	11	11	10	9	10	9	8
201 to 250, 369 to 400, 801 to 897	16	15	15	14	14	13	13	12	10	11	10	9

NATURE OF THE TRAINS and of the engines.	CATEGORIES OF THE LINES.													
	No 1.		No 2.		No 3.		No 4.		No 5.		No 6.		No 7.	
	Number of vehicles.	Weight.	Number of vehicles.	Weight.	Number of vehicles.	Weight.	Number of vehicles.	Weight.	Number of vehicles.	Weight.	Number of vehicles.	Weight.	Number of vehicles.	Weight.
7th. Trains running from 12 4 to 15 16 miles an hour (calculated speed slackening not included).														
101 to 176		110		100		90		80		80		70		
251 to 260	35	200	30	185	25	170	25	160	22	150	20	140	12	80
401 to 418-422-423-429, 281 to 311, 262-264-266 to 273, 321 to 328	35	220	35	205	30	190	30	175	25	165	20	150	15	90
337 to 348, 369 to 400, 424 to 428, 804 to 821	40	260	40	245	35	225	35	210	30	190	25	175	16	105
201 to 250, 401 to 418 (modif.), 801 to 803, 822 to 867	45	300	40	280	40	255	35	235	30	210	30	190	18	115
471 to 512	50	350	50	320	45	270	40	240	35	220	30	200	20	130
413 to 522	50	400	50	370	50	335	40	305	40	270	35	240	20	160
431 to 446														
541 to 575, 601 to 652	50	425	50	390	50	360	50	325	45	295	40	260	25	175
653 to 701	50	450	50	415	50	375	50	340	45	305	45	270	30	185
901 to 968, 969 to 974, 975 to 987	50	475	50	440	50	400	50	360	50	325	45	285	30	200

On the Northern system with relatively simple profile, a service order, of the 22nd of May 1875, regulated in conformity with the following table, *the normal load of the trains* by the type of the engines and according to the profile of the line.

NORTHERN. — NORMAL LOAD OF TRAINS ACCORDING TO THE TYPE OF ENGINES AND TO THE PROFILES OF THE LINE.

Numb. of the categories	INDICATION of the gradients one in.	INDICATION OF THE LINES or sections of lines.	INDICATION OF THE ENGINES. 51 à 121	2.401—2.551 2.821—2.845 2.951—2.985	3.201—3.274 (Original boiler). 2.621—3.662	3.201—3.274 (Boiler Crampton). 3.663—3.697	3.201—3.274 3.698—3.717 With large fire-box.	3.275—3.334 Original fire-box. 4.551 - 4.565 651-670 / 751-765 NB	3.335 - 3.452 3.275—3.334 Fire-box lengthened.	4.401—4.425 6.566—4.605	4.361—4.400 4.801—4.970 701-728 NB
			Units.	Units.	Units.	Units.	Units.	Units.	Units.	Units.	Units.
1	Up. hor. 0 to 200	The whole system save the lines designated below. ..... Paris to Creil (by Chantilly) and *vice versa*	45	80	84	94	91	120	130	140	180
2	Do. 200 to 166	Paris to Laon (by Soissons) and *vice versa* ..... Hazebrouck to Saint-Omer and *vice versa* ..... Lens to Arras and *vice versa*..... Lens to Bully-Grenay and *vice versa*.	41	73	76	86	91	109	118	127	162
3	Do. 166 to 143	Asnières to Sannois and *vice versa*. Laon to Crépy and *vice versa* .. .. Dompierre to Avesnes and *vice versa*. Etaples to Boulogne and *vice versa*. Amiens to Buchy and *vice versa*....	38	67	70	79	83	100	105	118	15
4	Do. 143 to 125	.....	35	82	65	72	78	92	100	108	138
5	Do. 125 to 111	Senlis to Crépy-en-Valois and *vice versa* ..... Aulnoye to Dompierre and *vice versa*. Boulogne to Calais and *vice versa*..	32	58	60	68	71	86	94	100	130
6	Do. 111 to 100	Marle to Laon and *vice versa*..... Avesnes to Fourmies and *vice versa*. Anor to Hirson and *vice versa*.....	30	52	55	61	66	78	85	91	117
7	Do. 100 to 90	Rouen to Buchy and *vice versa*..... Beauvais to Gournay and *vice versa*.	28	50	53	59	53	76	82	88	114
8	Do. 90 to 83	Marle to Vervins and *vice versa*.... Fourmies to Anor and *vice versa*....	26	47	49	55	59	70	75	81	104
9	Do. 83 to 76	Beaumont to Abancourt to Amiens and *vice versa*.....	25	44	46	52	55	66	72	77	99
10	Do. 76 to 70	Vervins to Hirson and *vice versa*...	24	42	44	49	52	62	68	73	94
11	Do. 66	Saint-Just to Roche-Condé and *vice versa*	22	40	42	46	50	58	64	68	88

No 404.

The principle of the *steam-carriage*, which utilizes the weight of the useful load for adhesion, seemed, at first sight, very applicable to the *Uetliberg* line, but the velocity admitted, 10 miles an hour at the lowest, is great enough for the adhesion of the motor alone to be sufficient for transmitting that effect of traction corresponding to that speed, and to its power. (Speaking more correctly, it is this condition which fixed the speed, for it could have been reduced below that figure without interfering with the utility of the line.)

But this decision was only come to after a profound investigation of the principle of the steam-carriage, by a commission composed principally of professors of the Polytechnic School at Zürich, that is to say of men who are both theoretical and practical.

A carriage of large capacity was wanted, and which could not have been installed entirely on the frame of the engine; the benefit of adhesion would thus have been applicable to a part of the engine, the radius of the curves not allowing the coupling of additional axles. Far from effecting an economy in the dead weight, a great carriage would be at the same time inferior, in this respect, to two small independent carriages, without taking into account the faculty of coupling on a single carriage, when that is sufficient.

The deliberations of the Zürich commission have thus resulted in a conclusion in agreement with that which we drew up in these terms in 1873:

" It is especially on steep gradients that the concentration of the motor and of the load is grounded; and even then there must be peculiar conditions of traffic to abandon the advantages, in general so evident, of the independence of the motor and the load (404). "

No 413.

Crossing of the St.-Gothard. The trace of the line of the *St.-Gothard* could not be comprised in this chapter, where its importance would have assigned it a prominent place. This hiatus cannot even now be filled up, for the definitive project is not yet decided on. The preliminary project, called *the experts'*, prepared by MM. *Beckh* and *Gerwig*, has been the base of ulterior investigations, which are being carried out now. Charged with the technical direction, M. *Gerwig* had the plan made out to the $\frac{1}{5.000}$th,

and to the $\frac{1}{2.500}$th, for the approach gradients to the great tunnel, with curves of level 16.4 feet apart, and produced an amended project which, while preserving the general features of the first, deviated from it however, almost throughout.

M. *Hellwag*, replacing M. *Gerwig*, in 1875, ascertained that the preliminary project of his predecessor was insufficient, and that it could not, particularly serve as a basis for the preparation of an estimate of any approximation. The first estimates were too low; the ground had not been studied; the line had not been set out; the results of a trial line leaving such enormous contingencies could not be relied on, especially under conditions of execution of almost unparalleled difficulty. The statement of this position of matters came on the public like a revelation. The States interested had accepted with too great confidence a figure which should only have been presented as a very reduced minimum, to which it would have been necessary to apply a coefficient greatly exceeding ordinary limits. Opinion, exaggerating the consequence of this miscalculation has gone so far as to consider the execution of the work as placed in question, including even that of the great tunnel. There is nothing of the sort. The boring of the rock is an operation apart, which cannot be effected by the transitory crisis which the execution of the approach lines is passing through.

For these latter, there was plenty of time; the investigations, a little too much delayed perhaps, could be completed, and so fix the definitive line, and the real expenditure, or nearly so. Such is the great task which M. *Hellwag* has already partly accomplished, by producing a new trace, which notably modifies that of M. *Gerwig;* it has been set out on the ground, and the plane made to $\frac{1}{500}$th, with cross sections to $\frac{1}{100}$th.

It satisfies, as needs scarcely be said, the conditions of the international convention, and which it will be well to bring to mind.

Curves. Minimum radius : 328 yards.

Gradients. Maximum rate of inclination : one in 40, except at need one in 38 between *Biasca* and *Lavorda.* This slight increase would allow, says M. *Hellwag*, of a considerable reduction in the cost of construction of that section.

Altitudes.	North end of the tunnel (*Goschenen*).... ...	3639 feet.
	South do. (*Airolo*)...	3756 »

The normal weight of the trains has been fixed at 350 tons drawn for goods, and at 100 tons for passengers. The mean speed ought to vary according to the gradients, from 10.56 to 7.46 miles, an hour for the first, and from 13.7 to 28 miles an hour for the second, the following table sums up the whole of these conditions:

LINES AND GRADIENTS	MEAN VALUE of the coefficient of adhesion f.	GOODS-TRAINS				PASSENGER-TRAINS			
		Number of the engines.	Adherent weight.	Weight drawn.	Speed.	Number of the engines.	Adherent weight.	Weight drawn.	Speed.
			tons	tons	miles		tons	tons	miles
Subalpine, one in 100.	$\frac{1}{6}$	1	38	350	10.6	1	25	100	15.5
Approach gradients, one in 40. .	$\frac{1}{7}$	2	52	350	7.5	1	38	190	13.7
Great tunnel, one in 172. . . .	$\frac{1}{-}$	1	52	350	9.8	1	3.	100	18.6

In order that the trace may adapt itself to this constant load of goods-trains, either with single or double traction, and by utilizing (unless in the tunnel) the power of a six-wheeled engine, of an eight-wheeled engine, and of two engines of this type, the gradients of the long tunnels, *on a curve of a radius inferior to* 437 *yards, will be lowered:* on the approach lines, from one in 40 to one in 43 or one in 45, and on the lines in the plain, from one in 100 to one in 111 or one in 118.

The rate of inclination can, on the other hand, be brought up from one in 40 to one in 38 (as was stated just now), on the portion comprised between *Biasca* and *Lavordo*, because the climatic conditions which are more favourable in that region than on the whole of the approach line, allow a coefficient of adhesion to be relied on, a little over 1/7th.

In the curves of minimum radius (328 yards) where the rise of the outside rail ought to be 6 inches on the Subalpine lines and 4 inches on the approach lines, this difference of level will be obtained by depressing the inside rail one half of that amount, and raising the outer rail the other half, in order not to affect the centre of gravity of the vehicles. The junction of a straight line with a curve will be effected by a parabolic arc having, for a curve of 328 yards radius, a length of 86 yards in the Subalpine lines, and 43 yards on the approach lines. This connection, which diminishes when the radius of the curve increases, becomes nil, on the Subalpine lines, for a radius of 2400 yards, and on the approach lines, for a radius of 1640 yards.

A tangent is interposed between two reverse curves. Its length fixed at 43 yards at least, for the minimum radius of 328 yards, diminishes when this radius increases, and becomes nothing when the radius reaches 2187 yards.

The load on the rails being 2.5 tons dead weight, and 5 tons at the most of useful load, the weight drawn, 350 tons, corresponds to $\frac{350}{75} = 47$ axles; which gives a minimum of 755 feet for the length of the train, the two engines and their tenders included. But the return-empties not allowing more than 40 per cent of the maximum load to be reckoned on, that is to say one more than 4.5 tons on the average of load on the rails per axle, it is necessary, in order that the power of the engines may be fully utilized, that the number of axles reach $\frac{350}{45} = 77$ axles, and the length of the trains 1.116 feet.

The sidings cannot thus be less than 1.150 clear.

It would have been a very serious matter, to break, by the laying down of horizontals at the intermediate stations, the continuity of the rise of the section of the approach lines. It was therefore decided to replace these horizontals by gradients, limited to one in 40.

We have dwelt (II, 445) on the aggravating influence of the length of steep gradients. The engines, often so badly utilized, at least for the slow trains, stiff on lines with slight gradients, ought on the contrary, to develop, on very steep sections, a very considerable and at times indeed unusual amount of work; they can only keep it up for a certain time, at the end of which they need a careful overhaul by the driver, a thorough lubrication, the fire raked over the pit, in a word, a stop, a slight rest, so to say, during which the motor recovers itself (without, of course, speaking of the feed, which ought to be insured by the correlative determination of the capacity of the tenders and the distances apart of the water-columns). About 6 $\frac{1}{4}$ miles are considered as the limit of the journey which one engine can make up one in 40, and with the load admitted. In an article published in 1875 (*), M. *Idoch* estimates at 9,4 miles the limit which the length of steep gradients should not exceed.

This limit is however, not absolute. Every thing else the same, it depends on the nature of the fuel, and the manner in which it burns on the grate. If it is friable, the small particles carried over into the smoke-box, finish by blocking up the lower rows of tubes; it is then particularly needful to arrange for easy modes of clearing out the smoke-box, and to clear out the deposits which have taken fire.

This condition reacts on the trace. It is not a question, in effect, of simply stopping the engine on a continuous up-gradient, which would be inconvenient and even dangerous. It is a question of regular stations, to be not more than six miles apart, and the position of which is determined not only as on ordinary lines, by the interests to be served, but also and indeed chiefly by the paramount requirements of the traction.

Others can be foreseen, but which do not affect the trace itself and which could be met in the course of working, when their nature would be thoroughly ascertained, as well as the points where they might become manifest.

Thus, in very unfavourable atmospheric conditions, goods-trains might be under the necesssity of taking in water between the regular stations.

(*) *Organ für die Fortschritte*, 1875, p. 109.

It might be thus necessary to establish, always beyond them, eventual sidings for goods-trains, which passenger-trains might have to pass.

This would be provided for by supplementary stations, composed essentially, without interfering with the main lines, of a water-crane and a siding on a horizontal connected with the rising line, and into which the trains would be shunted, according to regulation.

The establishment of stations at the two mouths of the great tunnel is looked on as indispensable. Their distance apart will be 9.45 miles, a figure considered, notwithstanding the low rate of inclination of the tunnel, as the extreme limit between the stations.

M. *Hellwag* adds besides that probably their special function will be the substitution of some different mode of traction in the tunnel for the locomotive.

The study of M. *Hellwag's* report cannot be too highly recommended to engineers charged with the execution of a railway in mountainous countries. They will find therein very useful considerations on the conditions to be fulfilled, and on the shoals to be avoided.

If the torrents which have prepared on both sides of the great chain of the Alps, a bed for the great artery in course of construction, allow the crest to be passed at a moderate altitude, we know at what price, the limit fixed, and very wisely so, for the rates of inclination one in 40, can be kept to.

In their most precipitous and contracted parts, the valleys of the Reuss and the Ticino are totally devoid of those cross valleys which the line could take advantage of to develop its length, and come out at times almost right above its entrance therein, having thus gained many hundred feet in height (*).

This means nature has refused to the *Saint-Gothard* line; art must make up for it by an extreme expedient, that is to say (II, 470) by *screws* cut in the rock, with an inclination of one in 20 on vertical cylinders, the minimum diameter of which is that of the curves of the line. No one of the three projects was able to get rid of this heavy burden, perhaps heavier still than is believed, of the *spirals*. They are only however the application to railways of the principle of zigzags on roads, a principle which might, in certain cases, become economically admissible if combined with cups; but these latter are rejected, and on very just grounds too, for great lines (II, 471).

Since the publication of the report from which we have been extracting,

(*) A very remarkable example and well known to all engineers, is the *Gossensass* development on the *Brenner*.

to an extent which will doubtless not seem excessive, a brisk impetus has been given to the investigations on the ground. According to the last report, dated the 31st of March 1876, No. 139 (*), of the *Federal Council* to the governments giving subventions :

" The investigations on the ground for the approach lines, north and south, are nearly completed. The preparatory phase has thus been passed, and conclusions drawn. A great number of trial-lines have been taken, and these have been compared with each other.

" The exceptional nature of that Alpine ground, and the extraordinary difficulties which the execution of the line will inevitably encounter, have for consequence that a very slight modification of the trace will involve a considerable difference in the cost. It has thus been necessary to proceed with the most thorough and most varied studies of the ground to find a trace which, while satisfying other conditions, should be at the same time the most economical. "

Is the question so far advanced? And if they are really in possession of the most economical trace, can they tell pretty nearly what it will cost? Somewhat optimist on the first point, the report maintains a significant silence on the second.

No 412.

Line from Vera Cruz *to* Mexico. The indicated conditions have received, in the course of execution, important modifications in the intermediate portion, which presents gradients of one in 33 and one in 25, and curves of 360 and even 325 feet radius.

The English stock, with wheel-base from 11.5 to 14.75 feet could not do for such a line; and it has been converted into American. The iron-frames have been connected two and two by long fish-plates, and the double vehicle thus formed has received at each end, a truck with a turning-pin.

No 433.

The engines in question do not appear to have given complete satisfaction. It results, in effect, from a note communicated to the *Société des Ingénieurs civils* (Paris) at the meeting of the 18th of May 1876, by M. *Desbrière*, that, as far back as the first months of 1875, two engines of a new type were put into work on the *Cantagallo* line. These engines, from *Gouin et Co.'s* workshops, belong to the same type delivered by the same firm to the temporary line over Mount-Cenis, that is to say that two cylinders only drive at the same time both vertical and horizontal wheels. The fault com-

(*) Folio, p. 5, *Wyss*, at *Berne*, 1876.

plained of with respect to the engine of the *Leeds* builders, was probably the frequent breakages of the parts of the machinery, for M. *Desbrière* states that M. *Gouin's* is completely exempt from these accidents. We have no data regarding this engine; but the principle itself, that is to say the supplementary adhesion obtained by pressure on a central rail, seems to us absolutely bad.

M. *Desbrière* mentions in the same note other engines of the same system, constructed at the *Avon-Side* works for the 3.6 feet line with gradients of about one in 145, in *New-Zealand.* These latter have four cylinders, but they do not belong to the *Manning and Wardle* type.

The central rail system is thus tried with a perseverance one cannot but admire, even while not believing in its future.

The various types with 2 and 4 cylinders, which worked on *Mount-Cenis*, are now on the *Cantagallo* line, where *Manning* and *Wardle's* engines and *Gouin's* new pattern have gone to join them. If the result is negative, the partisans of the principle cannot be accused of being discouraged too soon.

No 435.

The *Rigi* system is applied to the little line from *Rohschach* to *Heiden*, which is 3.42 miles long and ascends 1258 feet with a maximum inclination of one in 11, and radii of 262 yards.

The locomotives constructed at *Aarau* have the boiler set on the frame.

This little line, the service of which is not interrupted in winter, has passenger and goods-trains employed chiefly by the rich quarries of *Rohrschachberg;* the journey is made in half an hour.

No 437.

Air-brake of the locomotives on the Uetliberg *line.* The air-brake, as more powerful and more economical, has been preferred to counter-steam on the line from *Zürich* to the *Uetliberg* (III, 324) which will be mentioned again farther on. The lengthened experiments (from the month of May 1875 when this little line was opened), have fully borne out this preference.

As at the *Rigi*, the compressed air is driven into the atmosphere, escaping through a cock which the driver regulates.

With a load reaching 1 1/4 the weight of the engines, the train is stopped on the steepest gradients (one in 14.5), without the assistance of the ordin-

ary brakes of the engines and the waggons; these latter only serving to check the speed on the flat gradients, and for stopping at the stations.

An injection of water prevents the cylinders from heating. In order to profit by the heat of compression, an attempt has been made to return the mixture of compressed air and water through a large pipe, into the water-tank under the boiler. But the elevation of temperature was almost insignificant. The communication has however one advantage : it nearly does away with the disagreeable noise produced by the escape of the mixed current into the atmosphere. Let us add that the air-brake has its full power, only when all its parts, pistons, slides and cocks are quite tight. It is so when the apparatus is new; but the power would soon diminish, if the wear, particularly that of the piston segments (III, 192), caused leakage.

Altogether, the success of the air-brake, under such conditions, and at a much greater speed than at the *Rigi* (10 miles an hour instead of 3) (II, 437) should not pass unnoticed.

The reversing-lever at first applied to the engines in question, has been replaced by the screw (III, 425), all the more necessary, in general, as the running in backward gear is the most frequent, and on that account specially applicable to these, which run as much in *backward* as in *forward* gear.

As at the *Rigi*, the engine is always *below* the train, and is never turned. It descends with the lever placed as for the ascent, in *forward* gear, the reversing of the distribution resulting from the change in the direction of running. In case of being imperfectly in gear, the lever would thus have a tendency to go over behind, and might injure the driver.

No 441.

Trial of the Wetli *system.* — This system was tried on a small portion, (442 yards), of line commencing from the *Wädensweil* station, having an inclination of 20, and curves with a radius of 328 yards and 656 yards respectively. The engine-tender has three axles, the two end ones with driving and coupled wheels 2.91 feet in diameter, the intermediate one supporting the drum with helicoidal threads.

The space between the axles is 7.87 feet. The boiler, which is vertical, has a heating-surface of 495 square feet; the engine, with a small fuel supply of 9,45 tons, weighs 19,67 tons ; the toothed wheel, which is very heavy, may be reckoned in this calculation at 1,96 tons. The weight of the engine, already very considerable per square inch of heating-surface, is increased by the employment of materials of indifferent quality, cast-iron, etc. The

pressure in the boiler cannot be carried beyond 9 ats: and in the cylinder it is reduced to 6 ats.

It was feared that the screw could not be coupled with the driving-axles, but M. *Wetli* was not of this opinion, and the results of the experiments show that he was right. Still, when we consider the differences of the travel, measured at the rims of the wheels and at the threads of the screw, some slipping must necessarily take place, since these differences are much more likely to occur there than between the wheels only. With three coupled axles, the engine drew 60 tons, without including its own weight.

The small quantity of steam produced by the boiler only allowed a very limited speed. To reach 9,3 miles, it was necessary to reduce the load by $\frac{1}{3}$.

The motion was very smooth and even there was not the slightest shock between the threads of the screw and the chevroned rails; the starting was also very easy. A simple piece of mechanism allows the screw to be lifted or put in motion without stopping.

When raised, it continues to turn jointly with the wheels, but without doing any work, and this is the case on those portions of the line where there are no chevrons. When the driver lowers the cylinder, which is done by simply ungearing, it is clear that he cannot distinguish the point of concordance between the projections of the wheels and the line, but as soon as the adhesion of the driving-wheels is insufficient, in proportion to the inclination of the line, slipping commences, and the wheel comes in contact with the chevrons.

In descending, an air-brake acts on the screw, and regulates the speed without the necessity of having recourse to the brakes of the passenger-carriages.

The chevroned rails are made with old rails and are somewhat damaged, also their profile is not exactly suitable; still the wear of the screw-threads is very slight.

On the whole the results of the first experiments are decidedly in favour of the principle.

A commission, consisting chiefly of professors of the École Polytechnique of *Zürich* asserts positively that the *Wetli* system is superior to the ordinary toothed rack.

M. *Wetli* has been kind enough to inform me that the railway from *Wädensweil* to *Einsideln* is in course of formation, and that three locomotives have just been constructed on a new plan. Several improvements will also

be carried out on the line; the experiments will be renewed under normal conditions of working, and it will shortly be possible to pronounce an opinion upon the intrinsic value of a system which may be difficult to develop, but which is certainly not open to the initial objection urged against the employment of locomotives on steep inclines.

Nos 451 and 456.

On the stiffness of metallic cables with hemp cores. Admitting that the stiffness of hemp cables is known pretty nearly, that of metallic cables with hemp cores is most uncertain.

We have already said (II, *Additions*), that experiments made in 1863, at *Dusino* by M. *Agudio*, on cables of steel-wire, of diameter comprised between 0.6 and 1.0 inch, tend to substitute for the law of the square of the diameter, the simple proportionality to the diameter; so that the stiffness has for expression : $n \frac{d}{D}$ R, d being the diameter of the cable, D that of the pulley, R the tension of the cable, and n a numerical coefficient, going up to 1/2.

The report, quoted farther on, of the Italian commission charged to pursue the experiments of *Lans-le-Bourg*, admits this expression for want of experiments more worthy of faith, remarking (*) that it gives values notably greater than those to which *Coulomb's* and *Redtenbacher's* formula lead.

M. *Hirn* and M. *Reuleaux* consider the resistance due to the stiffness of metallic cables, as nearly possible to be neglected.

According to M. *Ziegler* (**) who has greatly studied transmission by metallic cable :

" What contributes to render the resistance due to the stiffness of metallic cables capable of being neglected, is that the cable, by reason of its elasticity, restores in unwinding, a portion of the work which it has absorbed in winding. With hemp cables, on account of their slight elasticity, it is quite otherwise. " (Note communicated by M. *Ziegler* to M. *Achar.*) (***)

The slight loss of work in telodynamic transmission (II, 461) appears to justify this view. But with the doubt, it is preferable to admit, until fuller information, the figures deduced from M. *Agudio's* formula.

(*) Sul piano inclinato di *Lans-le-Bourg*. Relazione della commissione governativa. *Roma*, 1876, p. 100 and 114.

(**) This engineer, who established the excellent transmission from *Oberursel* to *Francfort-on-the-Maine* (100 h. p. to 3228 feet) has published a useful memoir entitled : *Erfarungsresultate über Betrieb und Instandhaltung des Drahtseilbetriebs.* — *Winterthür*, 1871.

(***) *Annales des Mines*, p. 257.

No 468.

Application of the Agudio *system at* Lans-le-Bourg. With the assent of the governements that took part in the subvention, the primitive project of the *Lans-le-Bourg* inclined plane has not been carried out to the full extent. The development has been reduced from 2400 yards to 1460 yards, and the height risen through, from 1760 to 1150 feet, which gives a mean inclination of one in 3.80 with a maximum of one in 3.14, instead of one in 2.63. The radius of the curves is 164 yards.

The reduction of length has thus lessened the cost, while leaving intact all the difficulties, as well as the significance of the results obtained.

In the experiment, which was continued during several months, under the eyes of a great number of engineers of different nationalities, and of several special commissions (*), every thing passed as had been foreseen. One single modification was made in the mechanical arrangements. A movable coupling, with counterpoise, was substituted for the fixed coupling or rather for the dynamometer; the propagation of the tensions was effected too slowly, under the sole action of the weight of the chains for the great stretch of the cable.

The commission charged by the Italian ministry of Public Works to follow the whole of the experiments, has acquitted itself of that task with a care and assiduity which proved that it thoroughly appreciated the importance of the question.

We have no quotation to make from the descriptive portion of their report, dated the 17th of May 1876; but we reproduce, textually, in the original, the conclusions (**) drawn up after a thorough investigation, and which are in accord with those we ourselves drew up (II, 669) :

« 1° Dal punto de vista meccanico, il sistema *Agudio*, comme venne provato à *Lans-*
« *le-Bourg*, e praticamente applicabile e può riguardarsi siccome suscettivo di entrare
« nell' esercizio corrente della trazione ferroviaria.

« 2° La sua applicazione torna tanto più vantaggiosa quantò minore è la pendenza
« per rapporto a quella un pò eccessiva, del piano inclinato de *Lans-le-Bourg*, o per
« converso il suo effetto utile diminuisce alquanto cocrescere della pendenza, ma però
« in minor misura di quel che avvenga cogli altri sistemi nei quali il motore che cammina
« col treno, forma parte maggiore del peso di questo.

« 3° In qualsiasi caso, affinchè il suo effetto utile s'approssimi maggiormete all' effetto

(*) See the report, already quoted, of MM. *Gerhardt* and *Flaman*, engineers deputed by the Eastern of France Company.

(**) Sul piano inclinato di, etc... p. 45 and 46.

« utile teorico, fa mestieri l'evitare colla massima cura le deviazioni nella disposizione « della transmissione funicolare, ed impiegare puleggie di grande diametro, solidamente « impiantate.

« 4° Relativamente alla sua applicazione a lunghezze maggiori di quella di *Lans-le-Bourg* « mancano dati per apprezzare essattamente il valore della maggiori resistanze che ne « deriverebbero alla fune, et le quali pare che non cresceranno in raggione minore della « lunghezza.

« 5° Il sistema *Agudio*, con motore idraulico od a vapore, è ognora da anteporsi par « tracciati in curve, al sistema fonicolare à trazione diretta.

« 6° Il sistema *Agudio*, sia pegli incagli al servizio quando esso venga intercolato fra « linee esercite in altro modo, sia pella poca lunghezza in cui ogni sua tratta deve suddi- « versi, — le quali circostanze influiranno molto sul traffico possibile, non può, anche « esercito con motore idraulico essere risguardato siccome in mezzo *definitivo* di vali- « care le montagne, allorchè ostacoli insurmontabili non siano per opporsi alla costru- « zione di una ferrovia à locomotiva ordinaria con pendenze continuate per lunghi tratti « del 25 par mille, o poco più.

« 7° Il sistema *Agudio*, con motore idraulico, e preferibile in linea economica, alle loco- « motive *Fell* e *Riggenbach*, in ogni caso, laddove è disponibile una conveniente forza d'ac- « qua; in generale però la convenienza economica comparativa di quel sistema, in ispecie « quando dovesse applicarsi con motore a vapore, dependi anche molto dalle circostanze « locali e speciali, e la si dovrà dedurre par ciascun caso con opportuni calcoli di con- « fronto. »

Torino, 17 di Maggio 1876.

Those readers whom the problem of traction on gradients interests, and they are numerous, will be glad to learn the results of the efforts made by M. *Agudio* for improving his system, and extending the field of its applications.

1st. *Locomotor with six pinions.* There was not, at *Lans-le-Bourg*, perfect harmony between the sample, so to say, of the locomotors, and the fixed motors. Alone, one of the locomotors was too weak for utilizing the available power of 1000 horses. Together, the two apparatus had an excess of force and, consequently, of dead weight.

If it had been a question of regular working, a locomotor would have had to be arranged with an intermediate power of transmission, greater by about 50 per cent, and as a necessary consequence, spreading the effort of traction over a greater number of points of support, or teeth of the rack, six instead of four.

The two additional vertical shafts are driven (Pl. XIX, *figs.* 1, 2, 3, 4 and 4′) by a pair of large vertical pulleys B, let in between the extreme pulleys A A′, having, like the latter, a diameter of 8.20 feet and receiving movement from the cable by simple friction on the rims, widened out in consequence on each side of the grooves of the extreme pulleys. The

bearings of the latter have thus as in the *Dusino* apparatus (II, 456) a slight play which permits them to tighten between them the intermediate pulley without grooves B, in consequence of their tendency to come together under the tension of the cable.

It is easy to show that the additional pair of toothed wheels ρ ρ' (fig. 2) will be able to transmit its contingent, either the third of the effort of traction due to a gross-train of 60 tons, instead of 44 tons. The locomotor being supposed at the bottom of the plane, commencing its ascent, the tension of the line M N (*fig.* 4′) is only that determined by the strainer, that is to say 882 lbs. Applying the relation (II, 450), $P = 2\, e^{\frac{b\,S}{r}}$ which connects the tensions on each side of the arc S (in this case the demi-circumference) embraced by the rope, we see immediately:

1st. That the sum of the adhesions of the cable and the two extreme pullies is far superior to the tension which it ought to receive, that is to say to the tenth part of the resistance of the train (seeing that there are two cables and that their velocity is five times that of the train). We have pointed out (II, *Additions*, p. 866) the value $f = 0.56$ as deduced from experiment. Ulterior observations have proved that it is more prudent to take $f = 0.47$, a value which completely removes all sliding in the actual case, unless under the action of a violent jerk, such as too sudden starting, and then the sliding would be the safeguard of the cables. At the same time, the cable starts alone and light under the action of the turbines, and the train is taken on afterwards by the necessarily gradual tightening of the putting the pulleys into gear, so that a start too jerking is hardly possible;

2nd. That, similarly, the limit of the tangential efforts transmitted to the pulley B by A and A′, a limit estimated at the one-sixth of the pressures, is far superior to the effort which B ought to transmit to its pinion, and that then, there would not be any sliding of the pulleys.

Reversing. To the advantage of increasing thus by 50 per cent the tractive power together with a less increase in weight, the addition of two intermediate pulleys joins another; the apparatus becomes susceptible of running as required either in one direction or the other, under the action always in the same direction of the motor-cables: a property which would be very useful for station operations, where one of the modes of traction, locomotive or cable, would be substituted for the other.

If the extreme pulleys are let go and cease in consequence, to drive their pinions, the rollers *g*, *g′* (*figs.* 1 and 4) are moved up a little, by means of a very simple lever mechanism; they press back slightly the pulleys A, A′, which separate from B, and only then transmit the effort to them by the intermedium of rollers, which reverse the direction. The effort thus reversed ought only to be the one-third of the direct effort, seeing that it is only transmitted by the middle pinions ρ, ρ'; but that suffices, for it is only then a question of movements without load, and in every case on a horizontal or nearly so.

The increase in the tractive power requires a corresponding increase in the power of the means of stopping.

The number of jaw-brakes (II, 467) is carried from one to two (M, M′, *fig.* 1) and that of the block-brakes, from two to three on each side. Further, as had already been done

at *Lans-le-Bourg*, the rims of the contiguous pulleys can be tightened two and two in a sort of vice E, E′ (*figs.* 1 and 2), taking hold of the side faces.

The total resistance referred to the speed of the train, which can be thus developed, rises to 39 tons, namely:

		tons
Two jaw-brakes (on the longitudinal sleeper).....	$2 \times 4 =$	8
Three block-brakes (rack).....	$3 \times 7 =$	21
Four pinch-brakes (on the rims of the pulleys)..	$4 \times 2.5 =$	10
Total.....		39

a figure appreciably equal to the double of the component of gravity ($0.33 \times 66 = 19.8$ tons).

The jaw-brakes M, M′, the power of which is increased by grooves similar to those of divers friction transmissions (II, p. 437), do not destroy the longitudinal sleeper too rapidly, on condition of limiting its heating (like that of the shoes which take hold of the vertical shafts) by an abundant injection of water.

This brake is at the same time, chiefly a stand-by, necessary only for stoppages on the incline, and to supplement the other brakes, if they get out of order, or to rapidly check an excess of speed, which the train might wrongly have taken.

On such inclines, the efficiency of the brakes depends, in the highest degree, on the attention and skill of those who work them. Nothing inspired me with more confidence at *Lans-le-Bourg*, than the results obtained by men who had only had a very short experience in working brakes.

On a normal descent, the brakes of the vertical shafts are sufficient, even without the assistance of the waggon-brakes in order to regulate the speed.

The pinch-brake acts, like the block-brake, by slackening the speed of the vertical shafts, but it has this advantage that a slight pressure exerted on the rims, which are animated with great relative speed, is sufficient for giving a considerable pressure on the teeth and for developing immediately on the rims a considerable resisting force.

The locomotor with 4 pinions weighs 11.8 tons. The application of the two supplementary pinions involves an increase of 4.3 tons, or 35 per cent, for an increase of 50 per cent in the effort of traction.

2nd. *Application of the system simplified to relatively flat inclines.* It is useless to go over the point again, that the *Agudio* system is essentially adapted for very steep gradients. Sometimes railways have to be made in valleys formed of reaches separated by abrupt breaks, falls, where a very steep rate of inclination coincides with contractions which exclude lateral developments, or render them inordinately expensive. If the moderate inclination of the reaches, and their breadth are great enough to allow of the line being developed, with relative economy, to an extent suitable for locomotives, the *Agudio* system steps in to complete the solution by allowing the trains to be brought over the *falls* which separate the reaches, and its useful effect is so much greater, for an equal height overcome, the

steeper the incline, at least within very wide limits. The maximum corresponds to a rate of from one in 4 to one in 3.3 about, and it is notably less for a flat incline, such as one in 20, or one in 16.6. The system thus suits the first limit better, but in no way rejects the second. If it were otherwise, if, for example, the locomotor only worked with advantage from one in 10, there would remain, between that limit and one in 29, one in 25 at will, but which is too stiff for locomotives, a gap without solution. Fortunately it would not be so. The difficulty is surmounted by a reduction of the useful effect, a consideration which is secondary enough in all cases where the motive power, taken as much as possible from waterfalls, is in excess.

On flat gradients, besides, the application of the system can be greatly simplified. It is well to expatiate a moment on this point, in order to bring out a remarkable property of the principle, that is to say, the elasticity with which it adapts itself to very varied conditions of application, by simplifying itself in proportion as these conditions become simpler.

These inclines of one in 20, one in 16.6, decidedly excessive (excepting in some particular and secondary cases) for the locomotive, and too low for the most advantageous use of the locomotor, may present themselves in circumstances where it is of consequence to take them as they are, for example, for a temporary application, requiring above every thing economy of establishment.

The question has arisen lately, apropos of the incidents presented by the execution of the approach lines to the *Saint-Gothard*.

In the face of the necessity of fresh surveys of the ground, and the objections raised by the solution admitted in order to limit the gradients to the compulsory one in 40, it seemed in conformity with reason and with all the interests engaged, to insure first of all, by provisional measures, the continuous working of the line. The mode of traction and the trace admitted being kept intact in principle, the delay would only affect the execution of the portions requiring helices, A, B, C (Pl. XVIII, *fig.* 21), and would permit of examining more closely into this solution which is perhaps inevitable, but evidently very onerous for the construction, and may perhaps be a source of more serious difficulties for the working. These tunnels, on a gradient of one in 40, with curves of small radius, with mouths very close together, into which the wind will nish producing two contrary currents, will require, without doubt, powerful mechanical means of expelling the products of combustion of the locomotives.

The other works, particularly the boring of the great tunnel, which consitutes an operation apart, will follow their course, and a provisional line established in the bottom of the valley with its rate of inclination varying from one in 16.66 to one in 14.5, and

worked by locomotives, would establish the continuity, and provide for the present, while reserving the future.

We are here under the conditions which seem to us to reserve a provisional part, if not a definitive one, for the *Agudio* system, in the crossing of the great chains, when we wrote these lines, which may be perhaps appropriately repeated here :

" Not that it is however, destined to effect, as some have thought, a complete revolution in the conditions of crossing mountain chains by railways. It will often allow their traces to be thoroughly modified in their details, but not, I think, in their essential features. It will simplify, and that will be a great deal, the conditions of access on the flanks of the great chains, but it will not change, at least for important lines, the height of the crossing of summits... "

Let us bear in mind, before proceeding to the application of the principle to long gradients of from one in 16.66 to one in 14.5, that in M. *Agudio's* system, the effort of traction includes two distinct elements : 1st, the *direct* traction of the cable; 2nd, the tangential effort applied by the horizontal wheels of the locomotor on their point of support, that is on the teeth of the rack.

At *Dusino*, where the effort was divided between the two lines of one single rope, the direct traction was nothing.

At *Lans-le-Bourg*, where there was only one fixed motor, the direct traction was a fraction of the total effort equal to the ratio of the speed of the train to that of the cable, that is to say one-fifth.

On very heavy inclines, the magnitude of the tractive power, for even a moderate load, requires at the same time great relative speed of cable, and of the points of support, the *gearing*, the adhesion under its different forms, that is to say rendered independent of the weight, being quite insufficient.

On less steep inclines, the rack may be suppressed and replaced by the *Dusino adhesion cable*, provided that the means of stopping, in case of the cable breaking, be perfectly insured without the aid of the central rail, which itself disappears. The diameter of the motor-cable may thus be reduced, while only giving it a relatively moderate speed, leaving a greater part to direct traction in the effort of traction.

For inclines less still, this course may be pursued farther; if they are near those on which the locomotive with simple adhesion would be pas sable, if it were not for the lowness of the useful effect (II, 368), the adhesion

cable might itself disappear, the effort exerted by the locomotor being then transmitted only by the adhesion due to its weight; but for it to be so, the direct traction must enter for a considerable part into the total effort, in order to reduce in consequence, that which is transmitted by the adhesion, very limited, of the locomotor. In other terms, the relative acceleration of the motor-cable should be much less than in preceding cases.

Such is the starting point of the project presented by M. *Agudio* for the application of his system to the portions with relatively slight inclines of from one in 20 to one in 14.5, which would replace provisionally the definitive traces with inclinations of one in 40, where the development would be obtained by means of the spirals.

The speed of the cable would only be about double that of the trains, so that the effort of traction transmitted by adhesion would be hardly more than one half the total effort.

This amounts, definitively, to combining, in nearly equal proportions, direct traction and telodynamic.

There is doubtless something regrettable to encounter, in the use of stationary motors, the difficulties arising from adhesion employed as intermediate. To get rid of it, the inventor proposes to employ ballast on the locomotor to the extent of ten tons; we should prefer to keep intact one of the principles of the system, that is to say the weight of the locomotor reduced as much as the efforts to which its parts are subjected will allow. It would be necessary, in that case, to give a greater share to the direct traction, that is to say to reduce the speed of the cable, and increase correlatively its diameter. The advantages inherent to the use of the locomotor, would still exist in sufficient proportion to warrant its use.

It would be out of the question to discuss at length a conception which is only a project and which will doubtless remain so, at any rate as regards the *St-Gothard*. We shall therefore conclude by a brief description of the locomotor, as adapted to these new conditions, that is to say acting as the locomotive, by the adhesion due to its weight, reduced as much as it can be. It is represented by *figs.* 7 and 8, of Plate XVIII.

An endless steel cable, 1.10 inch in diameter, taken on by the adhesion of the grooves, of two motor-pulley and stretched by a coupling-screw, passes round the outside demi-circumferences of two pulleys A, A′ placed in the mean vertical plane of the locomotor, on the middle of the two axles *e*, *e′* carrying and adherent.

These pulleys, loose on the axles, do not carry them on in the rotation imparted to them by the cable. On each end of their naves, a pinion P is keyed, gearing with a wheel R R′ dis connected at will, by means of a clutch jointly with an intermediate driving shaft E, E which thus receives a rotatory movement in a contrary direction to that of the pulleys; connecting-rods and coupling-cranks *b*, *b*, *b*, *m*, *m*, *m*, transmit this rotation to the axles, bearing as in locomotives.

The diameter of the pulleys, is 8.04 feet as is that of the bearing-wheels ρ, ρ. The ratio of the diameters of the pinion P and of the toothed wheel R, of the intermediate shafts, is such that the velocity of transmission of the cable is 2.2 times that of the train.

Weight of the apparatus : about 15 tons.

Two different speeds have been admitted for the two classes of trains : 13.7 miles an hour = 20 feet a second, and 7.5 miles = 10.8 feet per second for the goods.

The corresponding speeds of the cable would be then :

Passengers $2.2 \times 13.7 = 30.14$ feet a second.
Goods..... $2.2 \times 10.8 = 23.76$ do.

In order to have either of these velocities at will, that is to say also the velocities at the circumference of the two motor-pulleys, the motor is composed of four *Girard* turbines (horizontal axis) two and two on each side of the motor-pulleys, and intended, two for passenger-trains, the others for goods. The first drive the pulleys by a gearing the ratio of which is $\frac{1}{2.7}$, the others by a gearing the ratio of which is $\frac{1}{5}$th.

The somewhat critical position of the undertaking of the approach lines of the great *Saint-Gothard* tunnel, has naturally stimulated the inventors and the partisans of the divers systems of traction on steep gradients.

M. *O. Zchokke* recently presented a project for a trace applicable to traction by locomotive with rack (*Rigi* system) on the gradients of one in 20 and one in 16.6 of the water-course of the two valleys.

These plans should be encouraged. If the existing crisis were to end by the adoption, at least provisional, of one of the new solutions presented, valuable elements for the general solution of the problem would be collected, even in case of failure; and perhaps the interests engaged in the execution of the *Saint-Gothard* line might be congratulated on this delay.

CHAPTER III (VOLUME III).

Nos 5 (and 30).

The uniformity of the distribution of pressure ceases to be admissible as soon as the thickness of the cylindrical side is not very small relatively to the inside diameter; this hypothesis would lead, in effect, in that case, to an absurd consequence.

Under the action of a uniform effect, all the concentric layers would take equal *proportional* extensions, and, consequently, different *absolute* extensions. The difference between the diameters of the two extreme layers, and, consequently, the thickness of the cylindrical side, would thus increase under the action of the internal pressure, while, on the contrary they diminish.

No 12.

Bituminous coals are troublesome in use; the cakes they form have to be frequently broken. To simplify the task of the driver and fireman, they apply in the United States, to these coals, various systems of grates, called *rocking-grates*, the bars of which can take, altogether, a more or less jerking and oscillatory motion, which detaches the sticking pieces and clears the grate.

These coals having to be put on in a very thin layer, the grate ought to have a large surface, and consequently great length, which necessitates the bars being placed across. They are in cast-iron, cast ordinarily in pairs, and are provided at the two ends with spindles which are taken by semi-circular spaces made in the longitudinal supports. Each pair carries at one end a lower lever, and all these levers are jointed on to a bar to which the fireman can impart, by means of an ordinary transmission, a backward and forward movement and shocks more or less violent.

Behind the grate is placed a fire-dropper, formed of a cast-iron plate, sometimes solid, sometimes with openings, upon which the fire is fed first, and it is then turned over round an axis parallel to the bars.

No 19.

The most significant element is the surface of the grate, the more so as it implies very nearly the *direct* heating-surface.

In the United States, the *total* heating-surface, with tubes of short length, is ordinarily 50 times the grate-surface.

No 23.

Ferrules are very little used in America, while the arrangement indicated at page 44 is frequently employed. The projection placed close to the tube-plate is produced by means of the *tube-expander*, a tool the form of which varies. One of the most used, *Presser's*, is a mandrel formed of several segments enlarged at the extremity, between which a conical core is driven by hammer, when the tool is placed in the tube. After the extraction of the core, the mandrel, contracted by a collar forming a spring, is easily withdrawn. The ends of the tubes are hammered down over the plate by a swage of the same tool, and sometimes by means of a tool like that represented by figure 9, Pl. I.

At the present time, a thin sheath of copper *ff* (Pl. XX, *fig.* 15), is often let in between the tube and the plate, which, on the inside, is prolonged a little beyond the projection, but which is not, like the outside ferrule tried in Germany (p. 44) brought down over the edges of the tube.

No 31.

Perforated stays are now in general use. The Munich conference has even recommended the boring of existing stays, in their places, notwithstanding the diminution of resistances resulting therefrom.

No 39.

We have said in this paragraph, on the subject of the water deposited in the cylinders : " Another fact, of paramount importance intervenes : the condensation which is produced during the period of expansion, independently of any subtraction of heat by the sides. " A word was omitted, but an important one, viz. " of paramount importance *theoretically*" which should have been said. This point has been at the same time treated very fully in Chapter VII of Book VII.

Nos **46** and following.

More than all others, the boilers of locomotives require plates of superior quality; this is the consequence of the increasing elevation of the pressure, and of the condition of reducing as much as possible the weight of the engine.

The partial use of plates of mediocre quality, and consequently thicker, may be justified, as we have seen (46, p. 93) by considerations of the distribution of the weight over the wheels; and yet regular ballast, easily concentrated in the most favourable position, is preferable in principle to this ballast diffused under the form of extra-thickness over a great surface of plate. Cast plates may possess the two necessary qualities, resistance and ductility, to a degrèe which ordinary plates could not reach, unless in the United States.

Cast metal ought therefore from motives different, but not less determining, become the prime material for locomotive-boilers, as it has for rails. It is long since naval engineers and builders went into the advantages presented by steel-plates for marine boilers. As for locomotives, disappointments were experienced, due in the two cases to imperfections in manufacture on the large scale. The mass of consumers therefore renounced cast-steel, waiting until the works, surer of themselves, were in a position to supply good plate, of a uniform quality, while others, like M. *May* (50) returned to *crucible* steel, believing that its superiority over Bessemer plate was worth its greater price, and M. *Webb* held to the latter, but adopting the plan, which every one cannot do, of making them himself. To this name, let us join that of M. *Adamson*, who uses *Bessemer* plate exclusively for his boilers, but after testing *each* plate. Their edges are planed, and the rivet holes bored through the two plates laid in place.

At the present tine, the period of uncertainty appears to have passed for cast plate, as it has for cast rails. The trade is in a position to deliver to boiler-builders products offering complete security, *after previous tests*. The failures might have been avoided by tests on reception, but they either amounted to nothing, or were badly devised. If plates possessing or appearing to possess the necessary properties, sustained afterwards, accidents, fractures, even spontaneous cracks, it is because these properties were gradually modified by the predisposition of the metal to take temper. A great amount of ductility, so indispensable for a metal subjected at first to manipulations which tend to change it, and afterwards in work, to incessant efforts of dilatation and contraction, is at the same time very significant

from another point of view, of the incapability of taking temper. But this incapacity, the most important character perhaps for safety, ought to be verified directly.

It is not an easy task to define the tests most suitable to show whether a material fulfils the most essential conditions of its purpose. It is necessary for this purpose to have made a thorough study of its properties. When they are supposed to be perfectly known, unforeseen facts arise sometimes to prove that this knowledge is still very incomplete.

Several years ago, for example, *Bessemer* rails were greatly in vogue on the lines, where they answered very well, when the detrimental influence, exerted by their resistance to the shocks of the notches in the foot was ascertained (49).

The really significant conditions ought to be ascertained, from the point of view of the work to be done, and the others removed. In the matter of rails, there is the *guarantee*. But of what use would that be for boiler-plates, when one defective plate may cause a disaster?

The Navy service of material has drawn up, in consequence of numerous experiments made under M. *Mangin's* direction, the rules to be followed for the reception of steel, which that great service uses under different forms. They were embodied in a ministerial circular, dated the 11th of May 1876; we take from that document all that concerns plates.

Classification of plates, angle pieces, and sectioned bars of steel. Instructions relative to their use in each category and to the tests they are to be subjected to.

"The conditions of receipt which the various specifications contain for supplies of plates or sectioned bars of steel, are not always the same for the steels intended for the same use. Divergences are found therein which are not explained and which may perplex firemen and smiths. Appreciable differences are particularly remarked between certain inspection conditions, and the results supplied by the tests. It is of consequence to establish the uniformity of these conditions by approximating them as much as possible to the results which can be obtained at the present day.

"The actual position of steel-manufacture allows at the same time of a small number of rules being laid down for the tests of plates and sectioned bars, and it to be believed that these rules will stand good for some time.

"In consequence, I have decided that the conditions laid down as follows, shall be henceforth common to all specifications of the kind.

STEEL-PLATES.

CLASSIFICATION BY DIMENSIONS.

" The limits of the dimensions of the plates to be ordered are indicated in the following table, in which the plates are classified, according to their surface, in five categories. "

The plates of the first category will be paid for at the price indicated in the tenders; those of the other four categories will have for value this same price augmented respectively by 2, 4, 6 and 8 francs per 100 kilograms.

Rectangular plates above 15.75 inches wide.

THICKNESS in parts of an inch.	MAXIMUM length in feet.	MAXIMUM width in feet.	MAXIMUM SURFACE IN SQUARE FEET				
			1st category.	2nd category.	3rd category.	4th category.	5th category.
0.059	12.30	3.94	»	21.58	29 64	34.98	»
0.079	13.12	4 27	»	26.96	32.29	37.67	»
0 098	18.58	4 27	26 96	29.64	34 98	40.36	«
0.118	22.97	4.92	26.96	34.98	43.06	51.12	61.89
0.158	24.61	4.92	32.39	40.36	48.34	53.72	64 58
0.197	26.25	5.25	37.67	48.32	53.62	59.20	64.58
0.236	25.53	5.91	40.36	51.12	56.51	61.89	75.35
0.276	32 81	6.56	48.42	56.51	64.50	69.96	81.73
0.315	32.81	6.56	51.12	61.88	69.96	75,35	86.11
0 354 0.394	32.81	6.56	48.42	59.18	69.96	81.73	96.88
0 433 0.473 0.572	32.81	6.56	40.36	51.12	59.20	69.96	86.11
0.551 0.591	32.81	6.56	34.98	45.75	56.51	64.58	81.73
0.630 0 669 0.709	26.25	6.56	26.96	34.64	45.75	59.20	73.3
0.748 0.787 0.827	21.33	6.04	24.27	29.26	40.41	51.03	»
0.866 0.906	19 67	6.04	21.58	29.64	40.41	51.03	»
0.945 0.984	19.67	5.25	21.58	26.96	37.72	48.34	»
0.024 1.018	19.67	4.59	21.58	26.96	32.29	48.34	»

Strips and Covering-plates.

THICKNESS in parts of an inch.	MAXIMUM length in feet.	MAXIMUM width in feet.	MAXIMUM SURFACE IN SQUARE FEET			
			1st category.	2nd category.	3rd category.	4th category.
From 0.20 to 0 32	32.81	0.33 to 1.31	21.58	29.65	37.72	43.06
— 0.35 to 0.51	32.81	0.33 to 1.31	29.65	37.72	43.06	«
— 0.55 to 0.79	32.81	0.49 to 1.31	21.58	32 29	43.06	»
— 0.79 to 1.18	32.81	0.66 to 1.31	27.05	21.58	32.29	43.06

" Plates not rectangular, but with rectilinear sides may be ordered. The category in which they must be placed, will be determined by the surface of the minimum circumscribed rectangle. These plates will be paid for at 1/2 per cent more than rectangular plates of the same category. "

" Every plate not comprised in the above classification will be subject to a mutual agreement.

RECEPTION-TEST.

" In order to insure the quality of the steel-plates, three kinds of tests will be made: cold tests, hot tests, and tests for temper.

1st. *Cold tests.*

" These tests will have for object the determination of the resistance to fracture and the faculty of extension of the metal, as well in the direction of the rolling, as in the perpendicular direction.

" The mean results of resistance and extension obtained in each of the two directions, will be established separately by means of five tests at least for each of them.

" For these tests, strips will be cut out of a certain number of the plates taken at random out of each delivery, care being taken to experiment on an equal number of strips in the direction of the rolling and in the perpendicular direction. These strips will be shaped in such a way as to have for section a rectangle one of the sides of which shall be 0.98 feet wide, and the other the thickness of the plate. At the same time, for thin plates below 0.20 of an inch in thickness, the middle of the testing strip will be reduced to 0.66 of a foot, and for plates 0.70 of an inch thick and above, this same dimension may be reduced to the thickness of the plate.

" The length of the prismatic portion subjected to traction will be always exactly 0.66 of a foot.

" In no case must the strips be heated.

" The strips will be submitted to efforts of traction increasing up to rupture, by means of weights acting directly, or by the intermedium of levers gauged with care. These strains must never be calculated according to the indications of the manometer, if the machine employed to produce them includes a hydraulic press.

" The initial load will be determined in such a way as to produce an effect of traction equal to eight tenths of the breaking strain calculated according to the figures given in the table below. This first load will be kept on during five minutes. The additional loads will be afterwards placed at intervals of time appreciably equal and of about half a minute; they will be calculated, as nearly as possible, at the rate of 690 lbs on the square inch of the section of the strip to be broken. The corresponding elongation will be noted for each load, and measured on the primitive prismatic length of 0.66 of a foot. The final elongation will be that produced under tension at the moment of rupture.

" No test-strip allowed to be sound must break under the initial load, nor give a final extension inferior to eight-tenths of the final extension required. The narrow plates, which will not allow of test-strips being taken from them crosswise, will only be tested in the direction of their length, that is to say of the rolling.

"The smallest mean loads per square inch of original section under which the test-strips should break, and the corresponding minimum elongation, are given by the following table. For plates, the mean results, which should be compared with the figures of this table, will be those which shall have been obtained in the direction of least resistance.

THICKNESS in parts of an inch.	STEEL-PLATES.			
	FOR CONSTRUCTIONS		FOR BOILERS.	
	Minimum mean load.	Minimum mean final elongation.	Minimum mean load.	Minimum mean final elongation.
	lbs	per cent	lbs	per cent
0.060	103.6	10	»	»
0.079 to 0.118 exclusively. . . .	103.6	12	»	»
0.118 to 0.158 —	103.6	14	»	»
0.158 to 0.197 —	101.4	16	»	»
0.197 to 0.236 —	101.4	18	»	»
0.236 to 0.315 —	99.2	20	92.6	25
0.315 to 0.787 —	99.2	20	92.6	26
0.787 to 1.181 inclusively. . . .	97.0	20	88.2	25
	STRIPS AND COVERING-PLATES.			
	LONGWISE		CROSSWISE	
	lbs	per cent	lbs	per cent
0.158 to 0.236 exclusively. . . .	105.8	18	97.0	16
0.236 to 0.630 —	105.8	22	97.0	18
0.630 to 1.181 inclusively. . . .	105.8	22	92.6	17

2nd. Hot tests.

"The test will consist in executing with a suitably sized piece of the plate, a hemispherical segment with the edge kept in the original plane of the plate. The diameter of the hemisphere, measured inside, will be equal to 40 times the thickness of the plate, and the flat circular edge will be ten times the same dimension in width; this flat edge will run into the spherical portion with a return, the radius of which measured in the inside of the angle will be, at the maximum, equal to the thickness of the plate.

"In addition, for plates of more than 0.20 of an inch, a trough will be formed with a square base, the sides standing up square; the base of this trough will have for its side thirty times the thickness of the plate, and the edges measured inside, ten times that thickness for height. The bottom of this trough will be bored in the middle with a circular hole with edges turned up perpendicularly to the plane of the bottom, and on the side opposite to that of the edges of the trough. The diameter of this hole finished, measured inside, will be twenty times the thickness of the plate, and the height of the edge turned up, will be five times that thickness. All the angles will be rounded off and their inside return will have the thickness of the plate for radius.

"The pieces thus prepared with all the precautions that the working of steel requires, should present neither cracks nor splits, even when they have been cooled in a rapid draught of air.

3rd. Temper tests.

"For these tests, strips will be cut out of the sheets offered for reception, 10.24 inches long by 1.57 broad in the direction of rolling and across; in any case, these strips will only be taken in the direction of their rolling when the question is to try jointing-strips and covering-plates less than 10.24 inches wide. These strips will be heated uniformly, so as to be brought to a dull red heat, then dipped into water at 82°.

Thus prepared, they should take, under the action of the press, without presenting any trace of fracture, a permanent curvature of which the minimum interior radius measured should not be more than the thickness of the strip tested.

"These same strips, when plates ordered for boilers are in question, should bear, under the action of the press, and without showing fracture, doubling in two, flat, in such a way that the two halves may be completely applied the one on the other.

"N. B. The bars prepared for these temper tests should not have their longitudinal edges rounded off, only the sharpness of the edge may be removed with a small file.

"The plates which do not satisfy the conditions herein set forth will be rejected."

The manufacture of iron-plates is not given up; it struggles on and improves its products, but it seems doubtful that it can reach the same degree of resistance and ductility as good plates of cast-steel. If homogeneity and the absence of welds are of less value for plates which, like those of the barrels of locomotive boilers, are not in contact with the fire, on the other hand, the greater resistance and, consequently, the less thickness and relative lightness of steel-plates specially designate them for the boilers of those engines.

We were speaking farther back of the attempts made to free the manufacture of what is called *cast-steel*, from the onerous necessity of employing chiefly pig-iron of superior quality. If this be accomplished for rails, which come under the class of steel, success may also be hoped for with respect to the plates for boilers. In this case, it is no longer steel that is required, but on the contrary a metal deprived, or more strictly speaking, disburdened of the characteristic property of steel, that of taking temper.

We can understand then, that minerals without any *steely property*, may and indeed ought to be preferable.

This is what the future will show; but until further notice, it is well to have boiler-plates from pig-iron of high quality only.

Trials made at random would have the risk of compromising success, and would cause all cast plates to be regarded with undeserved mistrust.

It is evident that the conditions provisionally laid down by the ministerial order of 1861, for the margin of thickness to be allowed for cast-steel plates, should be thoroughly modified. The figure of resistance might be less

exacting, but should be much more so for those of the elongations of fracture, which might be carried to the double, the length of the gauged portions being 8 inches.

Tests verifying the inability of the metal to take temper should be compulsory.

No 73.

The importance of safety-valves is such that we consider it useful to make some new observations on this point. Let us admit a forced evaporation, 22 lbs per square foot per hour of heating-surface. For a given pressure the density is deduced therefrom, and in consequence the volume of steam passed off, its velocity of escape, and therefore the section of the opening necessary to let it pass.

The central commission on steam-engines had made some experiments more than thirty-five years ago (*), in order to determine the necessary section for the escape of the steam produced by a boiler, in which the pressure was made to vary, as well as the evaporation per inch of heating-surface. To discuss the details of these experiments would scarcely be attended with interest at the present time; they in no way answered to the conditions of the problem. The experiments were made without valves, and and with open orifices. The value thus obtained is $d = 0.918\sqrt{\frac{S}{n-0.412}}$, S being the heating-surface in square metres, n the absolute pressure in atmospheres, d the diameter of the valve in square centimetres. By the application of the ordinary principles of coefficients of safety, the section was doubled to begin with, that is to say by multiplying d by $\sqrt{2}$, which gave $1.3\sqrt{\frac{S}{n-0.412}}$; then, in order to make allowance, rightly or wrongly, for the obstacle which opposes the escape through the greater or less obstruction of the orifice by a valve which does not cease to project over it, a new coefficient of security was introduced taken equal to 2, that is to say quadrupling the section, which is thus altogether multiplied by 8.

We see to what is reduced the part of the experiment in the determination of the formula $d = 2.6\sqrt{\frac{S}{n-0.412}}$.

The coefficients were taken in such a way as to bring in the final result

(*) *Recherches sur l'écoulement de la vapeur*, etc., par M. *Tremery*, ingénieur en chef des Mines. *Annales des Mines*, 3rd series, 1841, vol. XX, p. 347.

to the dimensions instinctively adopted by good builders, for boilers, at rather low pressures, then in use. In the absence of all experiment, on the escape of steam lifting a safety-valve, there was hardly any other part to take; but at the same time, the question was not advanced one step.

" The valves ", said in conclusion the report of the researches in question, " open by degrees up to the point of being sufficient for the escape of the steam, without any abrupt movement in the inside of the boilers resulting from that escape. "

These words " up to the point of *being sufficient* for the escape of the steam ", signify doubtless that the pressure can no longer rise, whatever may be the energy of evaporation. This assertion is then purely gratuitous, and we know now that it is quite incorrect.

As soon as the valve rises, it is no longer subjected to the pressure existing in the boiler, but to the shock of the fluid vein escaping therefrom, and rapidly expanding; and the valve cannot remain lifted if the inferiority of pressure of the vein, relatively to the statical pressure in the boiler, is compensated by an increase in the second; an increase which should be greater still, if, as in locomotives, the pressure to which the external face of the valve itself is subjected, is increased by the additional tension of the spring.

Too little importance is attached to the increase of the total pressure of the vein on the lifted valve, by making that vein act on a surface much greater than that of the orifice. This means is greatly in use on the United States railways. Figure 16 (Pl. XX) represents the valve founded on this principle, and bears the name of *Richardson*. The surface on which the jet of steam acts, in order to keep the valve raised, is very nearly double that on which the pressure of the steam in the boiler was acting.

The throat g, g has for object the increase of the pressure exerted by the jet, the threads of which undergo thus a greater deviation.

Let us cite an arrangement frequently applied, and always in the United States, to valves with a lever. The extremity of the spring is attached, not to a fixed point, but to a second lever l, which the driver can put into different positions by means of a ratchet. He thus regulates, at will, the tension and consequently the lifting-pressure of the valves. This method is much simpler than working them by a screw, which is often difficult to get at. Figure 12 (Pl. XX) indicates the ordinary arrangement; it is the manometer disc, which serves as a support, by its hind face, to the axis of the lever l and by its side, to the circular ratchet ρ, ρ.

No 94.

We have stated, and we do not fear to insist on this point, so great is its importance, that a nearly continuous feed has the advantage of reducing to a minimum the abrupt and local changes, and consequently the contractions to which boilers are subjected by the introduction of cold water.

But let us also repeat that on lines of varying section, it is chiefly the section which regulates the feed.

The drivers reserve the feed as much as possible to be done on running down inclines. Many of them see in that a motive for the use of pumps, the work of which then creates a useful resistance. The fact is correct, but its bearing is exaggerated. The work of forcing the water in, is of very little consequence.

No 97.

The purity of the feed-water ought not to be absolute. In that state, it would exert a corrosive action on the metal sides which has not been studied, but the actuality of which has been shown by experience.

Thus, marine boilers provided with surface condensers, are never fed exclusively with distilled water. The latter is always mixed with a small portion of sea-water, not only to make up for the slight leakages (which might also be done with distilled water), but in order to protect the surfaces, by a slight saline deposit, against the action of the pure condensed water, or rather mixed only with greasy matters.

No 114 (page 246).

The superheating is only produced beyond the *orifice*, and before the point where the jet is mixed with the air; it is this superheating, very rapid, which allows the hand to be exposed, even near the opening, to the action of the vein which escapes from a high pressure boiler. The water which alone burns, has disappeared.

We see besides what is the source of heat which produces the superheating. The jet rapidly loses its velocity, and its *vis viva* is transformed into heat.

Nos 115 and 116.

It is well to call to mind, now that the opportunity presents itself, that the mechanical theory of heat leads to the only values now in use, of the specific weights of saturated steam.

We have seen in this paragraph that

$$Ap\dot{u} = 51.98 + 0.096\,t - 0.00002\,t^2 - 0.0000003\,t^3,$$

p being the absolute pressure in pounds on the square inch, and t the temperature Fahrenheit.

Now, we know (114) that $u = s - \sigma$, s being the volume of the pound of dry saturated steam at $t°$, and σ that of the pound of water, which may be looked on as constant and equal to 0.0353 cub. ft.

We have then, γ being the weight of the cubic foot of steam.

$$\gamma = \frac{1}{s} = \frac{1}{u - \sigma} = \frac{1}{u + 0.0353},$$

u being the value drawn from equation (a).

It is in this way that the values of γ have been calculated comprised in *Zeuner's* table X, and which agree very well with those found by *Fairbairn* and *Tate* from experiment. They are, moreover, represented with a near approximation by the empirical formula $\gamma = 0.0177\ \pi^{0.9393}$, in which π is expressed in atmospheres; γ is always the weight of the cubic foot of dry saturated steam at that pressure π (*).

Let us call to mind that the relation (a) is derived directly from this :

$$\lambda = 1091.9 + 0.305\,t = q + r = q + \rho + Apu;$$

λ = the quantity of heat to be added to 1 lb of water at 52° in order to convert it, under the pressure p, into saturated steam at $t°$;

q, the heat necessary to carry 1 lb of water from 32° to $t°$;

r, the heat to be added to 1 lb of water at $t°$, in order to bring it into saturated steam at the same temperature.

ρ, the heat absorbed by the molecular work (*internal latent heat*).

$Ap\,u$, the heat absorbed by the external work (*external latent heat*).

(*) M. *Résal* proposed (a) the simpler formula $0.540\ u + 0.078$ exact to $\frac{1}{67}$th, between $n = 1$, and $n = 8.5$ (n pressure in atmospheres). This is very nearly *Navier's* formular.

(a) *Traité de mécanique*, vol. II, p. 473.

No 133.

In American engines, the blast-pipes debouch, either separately, or by a single orifice, at the base of the smoke-box, and consequently at a great distance below the chimney. An intermediate tube (*fig.* 14, Pl. XX), widened out below (*fig.* 14, Pl. XX), called a *petticoat* pipe, hung in the smoke-box, makes up for the most of that height. The drawing in of the gases is done at M and N.

The position of the exhaust and that of the chimney being given, the necessity of the intermediate pipe is understood. But what is the value of this arrangement, compared with that which prevails in Europe, in which the exhaust orifice is raised high enough to end nearly at the base of the chimney, which can be continued, when required, down into the smoke-box? It does not appear that experiments have been made to explain this point. In the opinion of American engineers who adopted the former method, it has the effect of distributing the gaseous current more uniformly between the superposed rows of tubes, especially by forming the pipe of two parts, one let into the other, which allows its length to be varied as well as the height of each of its extremities.

No 134.

In the United States, the pump is almost always preferred for feeding during running. The injector is reserved for standing.

The pump is always provided with an air-reservoir above the lower forcing chamber. Often also, one is applied below the suction-valve.

If the subject of the paragraph to which this addition refers (that is to say the condensation of a proportion more or less considerable of the steam in the tender) is of hardly any interest at the present time; if bringing the water up to, and keeping it at the boiling point, is generally given up, it is not a matter of indifference to be able, at need to bring it up above that, about 102°, which the improved injectors admit of; and this consideration explains the persistence with which the partial employ of pumps is retained on several lines. It is not only in this respect but also because they are interesting from other points of view, that it seems well to recall here the experiments made with M. *Kirchweger's* apparatus for measuring directly the influence exerted on the feed, by means of pumps, a small reservoir of air being applied to the suction-pipe immediately below the valve.

The water was stored (Pl. XX, fig. 13) in a tube R, which was put into communica-

tion by a pipe *t* with a ball valve-chamber *b*, taken from one of *Sharp* and *Robert's* engines, and provided with an air-vessel *c*. Above the chamber, was placed a large cock K, which was worked by hand in order to produce intermittence in the flow. The person instrusted with this operation regulated the movements of the crank *m*, and consequently those of the ball *b*, by the oscillations of a pendulum the length of which was made to vary, in such a way as to correspond to as many turns of the wheels, and consequently of speeds, as was desired. Each experiment lasted about 2′. The load was also made to vary. The experiments were made successively with and without the vessel, which it was easy to take off. The tank was gauged, and the expenditure reckoned by the lowering of the level.

Experiments on the influence of an air-vessel attached to the suction-pipe of a pump.

NUMBER OF TURNS per minute.	AMOUNT OF WATER PER MINUTE, IN CUBIC INCHES with a mean pressure of											
	18 feet 3 1/2 inches		Ratio.	13 feet 3 1/2 inches		Ratio.	9 feet 2 1/2 inches		Ratio.	3 feet		Ratio.
	with air-vessel.	without air-vessel.		with air-vessel.	without air-vessel.		with air-vessel.	without air-vessel.		with air-vessel.	without air-vessel.	
80	3.539.40	2.621.88	1.34	3.544.69	2.391.16	1.48	2.348.34	1.913.97	1.27	786.56	355.46	1.20
100	4.325.97	2.228.59	1.94	4.279.20	2.260.32	1.89	3.120.03	1.913.97	1.85	1.337.15	550.49	2.42
120	4.754.33	1.817.83	2.61	4.611.02	1.814.35	2.54	3.390.06	1.503.21	2.25	1.508.16	524.37	2.86
140	5.068.78	1.5C3.21	3.37	4.644.97	1.744.43	2.66	3.600.70	1.433.29	2.51	1.538 16	419.50	3.66

OBSERVATIONS.

1st. The volume of the air-vessel = 128 cubic inches.

2nd. The weight of the clack = 0.64 lb.

3rd. The diameter of the clack-seat = $1\frac{13}{16}$ inches.

4th. The smallest diameter of the pipe = $1\frac{1}{2}$ inches.

5th. The expenditure of water is for the case of 80 and 100 turns, the mean between 4 experiments, and for the case of 120 and 130 turns the mean of 3.

We see : 1st, that the velocity (number of turns) increasing, the expenditure increases with the air reservoir, while it diminishes without;

2nd, that at the speed of 140 turns, for example, the expenditure is greater under a pressure of 3 feet with the reservoir, than under the pressure of 18.25 feet without it; so that the influence of the air-vessel is then measured by a height of water of more than 15.4 feet. " Thus is explained ", says the report, " this fact, that some pumps with air-vessel, furnish, running at a *high speed*, more boiling water with the reservoir, than cold water without it.

No 157.

If the connecting-rods were supposed infinite, the two curves A M A′, A′ M′ A (Pl. V, fig. 49) would be symmetrical relatively to the right line A A′; the middle of the slide would coincide with the middle of A B′, and the two modes of regulation would be blended.

It results from this that, when *Zeuner*'s trace is applied, there is no question of two modes of regulation, as that trace neglects the obliquity of the connecting-rods.

Nos 161 and 168.

It is sometimes supposed that the *egg-curve* trace (*Fauvsau's* design) is given up.

This is not the case.

What is given up, is the trace of the *slide-ellipse*. When this trace is admissible, the much more simple polar trace of M. *Zeuner*, which, like the other supposes the connecting-rods infinite, is sufficiently approximate.

But the curve constructed by points (168), starting with the real elements, is the only trace which gives results sufficiently correct for engines with such great obliquities as locomotives, in which the length of the connecting-rod is only at times the quadruple of that of the crank.

No 174.

The principle of M. *Carels's* engine had been already indicated by a *Zürich* engineer, M. *Th. Gross*, and under special conditions which may justify its application.

It refers to engines intended for working at a very reduced speed on secondary lines with steep gradients.

With direct driving action, the smallness of the wheels thus requires a very short stroke of the piston, and a section consequently increased.

The interposition of a beam allows the cylinders to be kept to the ordinary dimensions. It is sufficient to give to the arm driven by the connectingrod a greater length than to the lower arm, the connecting-rod of which drives the cranks of the wheels.

The opposition of the movements of the two apparatus, upper and lower, allows the counterbalance-weights to be dispensed with, which are so difficult to place in wheels of very small diameter.

The beam realizes altogether, within certain limits, the same effect as the transmission by gearing, which has only been accepted at the last extremity, as in the *Rigi* engines, for example.

No 183.

The application of the distribution of the steam by valves has sometimes been tried in locomotives; according to Messrs. *Colburn* and *Clark* (*), an attempt was made in 1853 by Mr. *G. H. Corliss*, but was soon abandoned.

No 185.

The authors of the memoir, on *la Résistance des trains*, so often quoted, express themselves thus (page 84) :

" Large cylinders give much power for starting, but they expend a great deal of steam during running. "

Large cylinders expend what is wished; and, for an equal amount of work, they expend less steam than small ones, seeing that they allow of more expansion, instead of proceeding as was done too often, that is to say to allow the evaporation to languish in order to equalize it with the slight power of expenditure, of small cylinders, even with full admission.

It is besides clear that too voluminous cylinders, that is to say those only able to expend the normal production of the boiler with a very restricted admission, are of no more value than the contrary excess; but this latter, which is now more rare, was very frequent in goods-engines.

No 210.

The denomination of *dead-point*, applied to the middle of the link, ought to be given up, as being in opposition to facts, and as putting a driver's ideas wrong. So long as their personal observations, or sometimes chance, do not rectify their first impressions, they look upon the middle of the link as being the point of *efforts nil* on the piston. For them (and it is not for them only) one half of the link corresponds in an absolute manner to forward gear, the other to backward gear, so that the engine draws or retains the train, according as the point of the link, acting on the block, is placed above or below the middle.

(*) *Recent practice of the locomotive engine* (1860, p. 66).

Things are by no means so simple, as we have seen. The position which the *efforts nil* on the piston occupy, may vary between very wide limits; the engine, with the valve-motion already placed at high notch of backward gear, if that position is given it during running, may very well continue to draw, instead of holding back the train as was supposed, etc.

It would be well if facts of this kind, and their relations with the usual valve-motions, were pointed out by the superintendents to the drivers. Without going into experiments, for they have something else to do, they would find in the ordinary service many opportunities of ascertaining very nearly the position of the lever or the screw, to which the *efforts nil* on the piston corresponds, and consequently the real dead-point of the link.

They would thus arrive at a better knowledge of their engine and its resources, and would be able to produce a better result from it.

No 223.

The commission instituted at Berlin in 1873, considering that the opinions of locomotive engineers are very divided in Germany, as to the use of counter-steam, limited itself to expressing the desire that it might be, like the application of ordinary brakes to locomotives, the object of fresh experiments.

The commission recommended at the same time the stoping of wheels with spokes by means of a bar, especially in the culminating stations, as a necessary guarantee against accidents caused by the wind.

Counter-steam is very little used in the United States, where it is always the object of ill-considered distrust. It is at the most that they admit it as the last plank of safety. As to its regular use in working, with injections into the exhaust, there would appear to be no question of it. Mr. *N. Forney* expresses himself thus in his *Catechism of the locomotive* (*) :

" In case of a collision being imminent, all the brakes are made to act, then the steam is reversed; although it seems preferable, if one has the time, not to have recourse to that until the speed is already checked by the brakes, for the sudden reversing of the steam at a high speed may burst the cylinders, or knock out their bottoms, and break the pistons, etc... "

Same number.

Safety-lines. The correlative values of the length L and of the inclination

(*) *New York.* 1875, p. 5to.

$\frac{1}{i}$ of a safety-line intended to receive a train which is running away, down an incline, are evidently given by the relation : $\frac{1}{2}\frac{P'}{g}V^2 = P\left(r + \frac{1}{i}\right)L$, V′ being the acquired velocity, P the weight of the train, P′ this weight augmented by that of the wheels and axles, and r the mean resistance of the train.

It gives $$L = \frac{P'V^2}{2gP\left(r + \frac{1}{i}\right)}$$

Safety-lines may be applied with other views and under other forms : for example, to ward off the effects of the breakage of a coupling in a train mounting a heavy gradient, that is to say of running down backwards, or those of a goods-waggon pushed by the wind or that has got loose in shunting, from a culminating station; in this last case the safety-line may be reduced to a blind siding, or ended by a stop.

No 248.

On the skidding of the wheels by the brakes, and on slipping. How can the resistance due to a wheel pressed by an iron-block decrease when the pressure is increased so far as to skid the wheels? Whether the wheel turns or not, it is always the friction of iron : friction of the tire against the block before the skidding and of the tire on the rail, afterwards. If, with the wheel skidded, the tire becomes polished, with the wheel turning, it is the block; and one does not see why the coefficient should become lower in the first case than in the second.

It even seems that it should be the reverse, the rubbing-surface of the block being much greater than that of the tire sliding on the rail, and experience shows that the coefficient diminishes when the surface increases (II, 208).

There are also, in the slipping of the driving-wheels of engines, some rather curious effects.

When an engine in normal running commences to slip without any change occurring in the gradient, it arises from a local and accidental lowering of the coefficient; and as soon as it is passed, the tangential reaction of the rails on the driving-wheels undergoes an abrupt and very considerable fall, as is evidenced by the enormous increase in the velocity of rotation of the wheels, turning on the same spot; and this great speed, the effect of the sudden reduction of the coefficient, itself reacts thereon, seeing that it decreases, every thing else being equal, when the velocity increases, and

this increase by the fact of slipping is sufficiently great for its influence on the coefficient to be very appreciable.

If the slipping continues, the sliding on the spot polishes the rail, and the coefficient goes down lower still, on account of this change of state of the surface.

In running with counter-steam, the slipping, due to a reverse admission too long continued, occurs under quite different conditions; the wheels in that case do not slip *on the spot*. However, says M. *Gottschalk* (222), the engine no longer opposes any resistance to the descent of the train. " It is ", he adds, " *as if it were lifted.* "

We should be inclined to believe that there is only an illusion at the bottom of all this; that the resistance opposed by the engine slipping, a resistance reduced by the lowering of the coefficient which is at the same time the effect and the cause of the great velocity of rotation, is not however as slight as people imagine. When counter-steam is applied to a train driven at a high speed, in which a considerable *vis viva* is accumulated, the men are uneasy at the slowness of the reduction of the speed, and are inclined to attribute the fact to the *absolute* smallness of the retarding force, while that smallness may be only relative to the *vis viva* to destroy. All these effects are somewhat obscure, and it would be desirable to observe and analyze them with care.

The question of the influence of the skidding of the wheels on the resistance could be easily settled, and if experience established the reality of the fact in a positive manner, the explanation would no doubt be forthcoming.

As to that of the *direct* slipping of engines, it seems beyond doubt; it is explained by the double fact of the sliding on the spot, and the enormous velocity of rotation, at once the cause and effect of the lowering of the coefficient.

The effect attributed to reverse slipping in running with counter-steam, is less easy to understand, and in any case a sort of *lifting* of the engine, which M. *Gottschalk* seems to admit, can only be a figure, when it is a question of an engine the weight of which is adherent.

The slipping of engines may be attended with injurious effects on the machinery. It is therefore quite natural, that such a state of things would be hardly prolonged with the view of observing the corresponding value of the tangential reaction of the rails on the wheels. It would not however be without interest to risk some damage, a broken connecting-rod even, to arrive at an explanation of effects singular and at times contradictory.

No 264.

M. *Dietz*, locomotive engineer on the Eastern of France, has applied to the wooden blocks hung from the bodies, or on struts, a mechanism which compensates automatically for the wear (Pl. XXI, *figs.* 7 to 11). It consists in varying, very gradually, the point of articulation of the large rod on to the crank of the shaft. This carries an arc S provided with hooked teeth which takes by means of a gudgeon γ, on to the extremity terminating in a fork of the driving-rod B. One tooth corresponds to a determinate progression of the blocks of 1/2 an inch in the actual case. As soon as the limit fixed for the wear is reached, the rod B advances by one tooth on the arc S, and remains there until an equal fresh wear determines a fresh advance of one tooth, and so on until the block is quite worn out.

The working of the apparatus depends on a catch A, the mode of action of which is easily traced.

The trace (*fig.* 10) represents the position of the parts at rest; the trace (*fig.* 11), that which they occupy during the tightening.

At rest, the toothed arc S, which tends by its weight to turn towards the left taking the shaft O with it, is held in check by the catch A, which enters its pin α between the teeth of S, and butts, by the bottom of the groove $y\ z$, against the gudgeon G.

The guard turning the handle to put on the brake, the catch A, withdrawn from the pressure of the tooth, follows by its weight the movement towards the right of the arc S, until the inflection y of the groove (the branch $y\ x$ does not serve) has come up against G (*fig.* 11). It rests in this position while the brake is on; if, as we suppose, the blocks have reached the limit of wear, the arc S turns through more than one tooth, the pin α thus enters the tooth which follows, towards the left, that into which it was at first let.

The tightening accomplished, the gudgeon γ of the rod B must equally advance one tooth, and the catch retake its initial position (*figs.* 7 and 10).

The guard turning the handle m in a contrary direction, the stud E, fixed on the side of the rod B in the plane of the arc S sends the latter towards the left; S itself pushes over A, forcing the groove $z\ y$ to slide on the gudgeon G, and thus brings A to the position of rest. S is then locked, so that the movement of the handle continuing, the gudgeon γ of the rod lodges against the tooth which follows that which it at first occupied.

The small block-cranks are replaced by eccentrics k, k, keyed on the

shaft, and which press against bearings with edges p, p, adjusted on the rods b, b.

No 267 (page 535).

The Austrian *Staats-Bahn* proposed at the *Dresden* conference, to fix as follows the number of brakes correlatively to the speed and the section :

GRADIENTS one in	SPEED IN MILES AN HOUR				
	14	19	24	28	38
	Number of waggon-axles with brakes per 100..				
500	6	9	14	19	32
333	7	10	15	20	33
200	8	12	16	21	35
149	10	14	18	23	37
100	12	16	20	25	39
80	13	18	22	27	41
59	14	21	25	30	44
50	20	24	28	33	47
40	24	28	32	37	57

It is unnecessary to say that they run neither at 38 nor even at 28 miles an hour on gradients of one in 40.

No 270.

The police regulations in force since the 1st of January 1871, on the railways of the Northern German Union (*), fix 5 minutes for the minimum running over one German mile (4,66 English miles) by fast trains, when the rate of inclination does not exceed one in 200 and when the radii of the curves are not below 1094 yards. On stiffer gradients and curves, this time should be " suitably increased " (art. 25).

The *Berlin* commission (1873) thinks that this velocity (56.5 miles an hour) is too high, and that it is desirable to make a reduction to 45 miles an hour, that is to say to reduce the minimum time for running one German mile to 6 minutes.

To the restrictions arising from the trace, the commission proposes to add others in connexion with the conditions of construction of the engines :

1st. The minimum of 6′ would only apply to engines with driving-wheels from 3.58 to 6.56 feet in diameter.

(*) Bahn-Polizei-Reglement für die Eisenbahnen im nordeutschen Bunde (*Statistische Nachrichten von den Preussischen Eisenbahnen*, t. XVII, *Berlin*, 1870, *Ernst and Korn*).

2nd. The minimum would be raised to 8′, for engines with overhanging fire-box, and on condition that the wheel-base were not less than 11.32 feet.

3rd. This same figure of 8′ would be applied to engines with four wheels, provided the driving-wheels were not less than 4.92 feet in diameter, and the wheel-base 8.20 feet.

4th. The minimum time would be increased to 10′ for other engines.

5th. On account of the relative unsteadiness of engines running alone, the minimum would in that case be increased by 2′.

The conference of Mechanical Engineers, held at *Mayence* in 1871, went in some respects further still; it proposed for absolute minimum, 9′ per mile.

Seeing the divergence of opinions on the effects of the articulation of the leading-bogie, the commission drew up no special propositions for this class of engines; it only recommends not to apply engines with 6 wheels coupled to the traction of trains running at the maximum speed it proposes.

This recommendation would be superfluous, in the face of that which fixes 5.58 as the minimum diameter of wheels of engines authorized to run at the maximum speed.

These rules seem to us too minute, and not to rest on sufficient grounds. The stability of an engine does not depend solely on the elements considered by the commission.

But we fully coincide in its opinion on the following point :

1st. The exclusion, as complete as possible, from all fast trains, of all parcel-vans (Eilgutwagen) (which of course implies, *a fortiori*, the absolute exclusion of all slow goods-waggons).

2nd. Suppression, at the time of the coupling, of hooking on the guard-chains. These chains would remain, but only as a resource in case of a broken coupling (a proposition unanimously adopted) (*).

3rd. The reduction, as far as possible, of the length of fast trains; the fixing at 150 the maximum number of axles in goods-trains; a load regulated as much as possible so that one engine may in general suffice to draw them, without however excluding double traction where that becomes necessary.

Let us add that the commission condemns as dangerous, the habit of walking along the foot boards, for examining tickets during running.

(*) See p. 940, M. *Dietz's* coupling.

Nos 284 and 286.

Experiments on Smith's brake. The Northern of France has been experimenting for some time on two continuous brakes; it chose *Smith's* (284) and *Achard's* (286) that is to say the most simple, and most complicated.

The first was applied to an ordinary train, which by its numerous stoppages is better adapted for the tests than direct trains, and does not at the same time exclude speed.

The apparatus, set up by an American, is rather roughly made. Under the engine, the tender, and each of the vehicles is placed a sort of bellows, in india-rubber and with cast-iron bottoms, one fixed, the other movable. Iron-rings, from 466 inches apart, regulate the lowering of the cylindrical side where the vacuum is made; the movable bottom yields and drives the rod of the brake.

The apparatus acts, in the single engine (*Crampton*), on the two pairs of carrying-wheels, and in the other vehicles, on the four wheels.

The pipes are connected from one vehicle to another by flexible junctions protected from collapsing by spiral springs placed within them.

The exhaust is produced simply by a small *ejector*, placed in the front of the engine, on the side of the smoke-box and debouching in the chimney. Figure 20, Plate XVII, taken from *Forney's* Catechism, represents this little apparatus under the form given to it in the United States; it will be seen to be a special *blast*, acting like that which produces the draught.

The driver has only to work two organs; the steam-cock, and the valve D which serves to establish or interrupt the communication with the atmosphere. When at rest, the cock is closed, and D intercepts the communication with the atmosphere. As soon as the first is opened, the brakes are put on.

To take the brake off, the driver closes the cock, opens D, the air enters and the blocks are taken off instantly.

In the apparatus on the Northern of France, the release-valve is replaced by a simple vertical stop falling freely against the orifice of a suction-pipe turned at right angles, exactly closing by the vacuum itself, and which the driver has only to lift up.

The *ejector* recently adopted by M. *Westinghouse* for the *vacuum-brake*, differs in some points from the original apparatus. The suction of the air is produced, not only by an annular jet, but also by a central jet of steam.

The results of the tests on the Northern have been most satisfactory. The stoppages are very rapid, and very smooth, exempt from vibration (the pres-

sures exerted on the wheels are limited in such a manner that skidding never takes place, although the blocks are of wood) and from mutual reactions between the vehicles, a natural consequence of the distribution of the means of stopping between all the elements, which lose their speed simultaneously.

The influence of the air entering is slight. A train in which the pipes had been purposely left open behind, was stopped, more slowly of course, but more rapidly than might have been imagined.

Several stoppages were also made without closing the regulator, and the link at the ordinary admission of about 1/3. The fact is explained, besides. The suction in the tubes gained by the partial vacuum produced in the chimney as well as in the smoke-box, by the blast. The opening of the steam-cock of the ejector would be sufficient therefore, of itself, to stop the train, a point connected with automatic actions now being worked out on the Northern, and by which the putting on a stoppage disc may be manifested under different forms on the engine itself.

The following are the results of two of the observations made by M. *Banderali*, one of the engineers :

Friday 1st September 1876

STOPPAGES	SPEED at the time of putting on the brakes	GRADIENTS of the line		DISTANCE run through to complete stoppage.	TIME occupied in doing the distances.	OBSERVATIONS
		Down.	Up.			
Train 119						
	miles			feet	second	
Saint-Denis ...	37.0	»	»	607	24	Rails dry.
Pierrefitte	23.6	»	384	387	18	do.
Gonesse	24.2	»	»	384	20	do.
Gossainville ...	28.2	»	»	558	21	A little sand used.
Louvres	20.5	»	1000	374	17	Rails dry.
Luzarches	35.4	1000	»	866	27	Rails damp.
Orry-la-Ville..	44.7	1000	»	1050	26	Rails greasy and curve.
Chantilly	39.8	1000	»	846	23	do.
Creil	42.3	200	»	951	20	Rails dry, straight line.
Train 118						
Louvres	40.4	1000	»	820	22	
Goussainville..	39.2	»	»	768	20	
Gonesse	38.6	200	»	1066	21	Brake on during 164 yards on one in 200 down and the rest on a horizontal.
Pierrefitte	33.6	200	»	637	22	55 yards on one in 200 down, and the rest on one in 187 down.
		187	»			
	33.6	»	»	620	20	

Train 119 was composed of 12 vehicles provided with brakes, drawn by the *Crampton* engine 166, equally provided with the brake, as well as its tender.

Train 128 had besides two horse-boxes on leaving *Chantilly*.

It is sufficient to see this brake in action, and the distrust at first excited will by the principle of transmission be for the most part dissipated. Here there is neither mechanism, complicated organs, nor massive parts, subjected to great strains. The effective pressures considerably limited by the principle itself, cannot strain the tubes, and the india-rubber bags, yielding freely, only undergo a simple bending, which they can probably resist for a length of time.

The driver draws a small rod, and in a fraction of a minute the train is stopped, without noise, or sound of a whistle, or without either the fireman or the guards having touched their handles. They have become, from this point of view, simple lookers on, having no active part to fulfil unless in the case of the apparatus getting out of order, or of an accident such as a coupling breaking.

The principle of this atmospheric brake has long been known in France, where it was proposed by a very intelligent engineer M. *du Tremblay*, chiefly known as an inventor of combined steam-engines; a deceptive invention, as may be easily proved at the present time, but which the ablest minds accepted as a real progress before the mechanical theory of heat was propounded and its principles proved to be incontestable.

If the figures above quoted are compared with those given by other experiments, it must not be lost sight of that, on the Northern, the train was not completely braked. The counter-steam did not act, there was a deficit equal to the load of the driving-wheels on the rails, that is to say nearly 14 tons, the limit of weight in the *Crampton* engines ballasted behind.

The partisans of the two brakes, with compressed and atmospheric air are struggling, but with unequal success, especially in the United States. The first are carrying the day. Compressed air ought, in effect, to be more rapid in its action. The necessary work for tightening up the blocks is produced previously and stored up in reservoirs; while in the rival system the time required for the production of the vacuum has to be added. The brake called automatic has thus, as to the principle, a certain superiority over the vacuum brake, which Mr. *Westinghouse* now seems to give up after seeming to return to it.

The precise value of this advantage remains to be proved, and whether it

is not compensated by less simplicity of the apparatus. Such as it is, the *Smith* brake presents so striking a superiority over hand-brakes (which there is no intention of suppressing at present) that we should be only too happy to avail ourselves of its protection, without giving up, of course, the automatic brake, if experience shows that it offers more complete guarantees.

We persist at the same time in believing in the future of the principle mentioned further back (283), whether the fluid be compressed air, as in the *Rigi* and the *Uetliberg* engines, or the employment of water may be successful. To convert the *vis viva* of the train into heat by the friction developed between the tires of the wheels and blocks, is altogether, rather a barbarous method; to leave the first intact and suppress the others, would be a real progress from more than one point of view, notably as regards the axles.

No 287.

We could have desired to show the reader the official account of the experiments in question.

To a request with that view, the *Board of Trade*, to whom the author is indebted for much courtesy, made the following reply:

« .....Upon the receipt of your letter, the *Board of Trade* at once communicated with « the commissioners, and has been informed that the Report upon continuous brakes « on Railways, will be not issued until the commissioners issue their general Report « upon railway accidents.

« When this Report is issued, the *Board of Trade* will have great pleasure in for- « warding a copy to you. »

« I have, etc. »

A document of such importance is naturally looked for with much anxiety, not less in France than in England.

The Royal Commission on accidents has not yet published its report. This long delay causes a certain amount of surprise in England, the expression of which is found in the special journals.

It finds therein, and not without some show of reason, a justification of the inertness of several companies as regards continuous brakes, so unanimously demanded for fast trains.

No 288.

On the hydraulic brake tried at Lans-le-Bourg. The insufficiency of the resistance of the organs is not the only fault that experience has brought

to light. An unforeseen difficulty has started in putting into execution this method, theoretically so powerful.

The feeding of the cylinders requires in the tank a pressure more considerable than had been supposed; the working of the air-pump which serves to keep up that pressure, and the continual examination of the indication of the manometer, absorb too much of the driver's attention. A vacuum in the cylinders might be the cause of breakage and of accidents, the other brakes, very much simpler, are apparently sufficient, even on gradients of one in 3.3, and with greater reason, below that figure, the hydraulic brake has been given up. We have already stated that the idea was entertained of griping between two screw-jaws the sides of the rims of the great pulleys.

At the limit, this might be done and without the aid of the brakes applied to the vertical shafts, as far as the locking of the pulleys and consequently of the pinions of the rack, that is to say up to stoppage.

No 300.

A part of the phrase has been omitted here: At the end of these words: " that the difference of these velocities is not too great " the following must be added: " in general, provided the length l is great enough, the second member of the equation (1) independent of l, is very small against the second term of the first member, proportional to l. "

No 307.

The directors of the *Cologne* and *Minden* line have made, with a special train, a very numerous series (236 experiments) in all seasons and over the whole line. The resistance was measured by the dynamometer.

At the mean speed of 22.2 miles an hour, the resistance referred to a level was 4.92 lbs per ton, a figure which very well agrees with those of the *Lyons* line experiments.

It is perhaps a little less in reality, because it includes the influence of the curves, which are rather stiff, and that of the wind, which no great care was taken to avoid.

No 315.

A fourth axle has also just been applied on the *Orleans* lines, to the engines which draw the fast trains between *Paris* and *Bordeaux*.

No 324.

As we indicated in this paragraph, the use of sand is no longer rejected except in principle, on the line from *Zürich* to the *Uetliberg*. They wished to dispense with it, as complaints are made that it wears the flanges and the rails, and increases the resistance to traction; but the fact is that it is used. The drivers prefer it to water, which is in no way surprising.

The latter had a double object: 1st, to wash the rails when they are dirtied by matters forming a sort of paste, and to bring up the adhesion by placing it under the same conditions as during rain, when it is considered as equal to that of rails *clean* and dry; 2nd, to reduce the griping of the flanges in curves of small radius. Hence a double injection, taken either from the boiler itself or from the Giffard's injector. But a continued injection on the rails expends a great deal of water, and if recourse is had to it only when slipping begins, it acts too late.

On a line where the engines often work close to the limit of adhesion, it was essential to try all means of preventing its accidental lowering. The ballast being rather clayey, it was found necessary: 1st, to keep the sand to the lower level of the rails (*Vignoles* of 65 lbs); 2nd, to direct the jet of the blow-off cocks, not in front, which projects water more or less greasy on the rails, but sidewise.

Let us conclude by an observation entirely in favour of the mode of traction adopted. It is a question in this case, not of a line in normal conditions of traffic, but a promenade line, so that when the weather is bad, and consequently the adhesion low, the load is light also.

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